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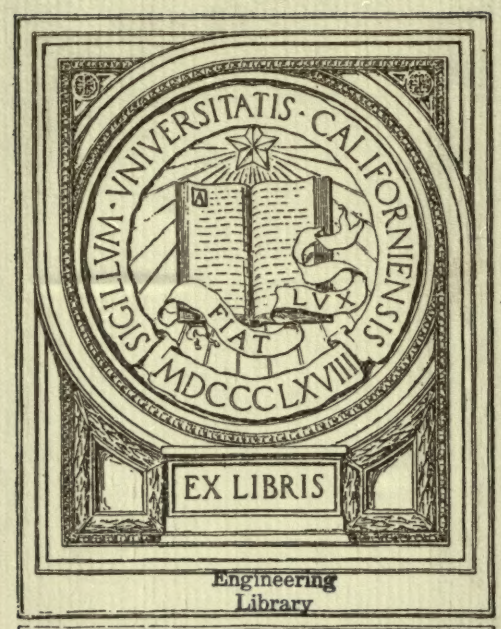

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Dear Professor Derleth:

I take pleasure in transmitting to you a copy of the Extension Division Correspondence Course MATERIALS OF ENGINEERING CONSTRUCTION, the multigraphing of which has just been completed. I thought that you might like to have a copy in the department files.

Sincerely yours,

C. T. Wiskocil

Professor C. Derleth Jr., Dean,
College of Civil Engineering,
C a m p u s.

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EXTENSION DIVISION.

Correspondence Course

MATERIALS OF ENGINEERING CONSTRUCTION

Civil Engineering 8.

By

C. T. Wiskocil

Associate Professor
of
Civil Engineering.

A Course of Thirty Assignments,
In Two Parts, 8a and 8b.

1922

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Correspondence Course

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UNIVERSITY OF CALIFORNIA EXTENSION DIVISION

Correspondence Courses

Materials of Engineering Construction

Civil Engr - 8. Professor C. T. Wiskocil

P R E F A C E

The Course in MATERIALS OF ENGINEERING CONSTRUCTION will consist of 30 assignments, or lessons, of mimeographed material which will be sent out by the Extension Division of the University of California. The course will be divided into two parts, designated 8A and 8B, each part consisting of fifteen assignments. University credit in the amount of two units will be given on the completion of both parts of this course. The textbook which is to be used is Johnson's "Materials of Engineering Construction", published by Wiley & Sons. It may be obtained from the Associated Students' Store, Student Union Bldg., Berkeley, California, for $6.20, postpaid.

Books on MATERIALS usually contain more information than is necessary to give you a working knowledge of the subjects treated. These books are excellent sources of information and with proper guidance they can be used as texts. JOHNSON'S MATERIALS OF CONSTRUCTION, which has been used for the past two years at the University of California, is such a book. To use it effectively, however, it was necessary to continually maintain the student's interest. This was done by informal talks, in which the important information was pointed out, and by frequent questions on the essential facts discussed.

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Since university credit in the Extension course in MATERIALS can be secured only by passing supervised examinations similar to those taken by resident students, it has been decided to use JOHNSON'S MATERIALS OF CONSTRUCTION as the text-book and parallel the resident-course still farther by supplying notes to take the place of class-room lectures and discussions. The purpose of the notes which will accompany each assignment is to assist you by emphasizing, explaining, and supplementing the subject matter assigned in the text. A set of questions will also be sent out with each assignment. You should test your knowledge of the subject by answering these questions without reference to the notes or text-book. At every opportunity, you should secure first-hand information by observing all examples of occurrence, manufacture, or use of the materials you are studying.

UNIVERSITY OF CALIFORNIA EXTENSION DIVISION

Correspondence Courses

Materials of Engineering Construction

Civil Engr. 8. Professor C. T. Wiskocil

INTRODUCTION

The purpose of this course is to present information concerning the mechanical and physical properties of the principal materials of engineering. A knowledge of these properties is necessary for the intelligent selection and use of materials for given conditions or service requirements.

Since the adaptibility and limitations of materials depend upon their mechanical and physical properties, it is important to know about the modes of occurrence, methods of manufacture, or preparation because variations in these factors affect the properties. Other subjects properly discussed in this course are: testing of materials and the fatigue and corrosion of metals.

Information on materials is obtained from various sources. Most of the data on the properties are compiled from the published results of investigations and researches while the principles involved in the occurrence and manufacture are taken from treatises on Botany, Ceramics, Chemistry, Geology, and Metallurgy.

Each material will be discussed in sufficient detail to bring out the desired information. It would be beyond the scope of the course to exhaustively treat each subject or to take up all engineering materials. The course will be given in accordance with the following outline:

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Materials of Engineering Construction

Civil Engr 8A. Professor C. T. Wiskocil.

Assignment	Subject
1	Mechanics of Materials
2	Machines and Appliances for Testing
3	Testing of Structural Materials
4	Uses and Physical Properties of Wood
5	Deterioration and Preservation of Wood
6	Mechanical Properties of Wood
7	Building Stone
8	Structural Clay Products. Specifications for Paving Bricks
9	Portland Cement
10	Results of Tests on Cement. (Natural Cement)
11	Lime and Plasters
12	Testing of Hydraulic Cement
13	Making of Mortar and Concrete
14	Mixing, Placing, and Curing of Concrete
15	Proportioning of Concrete

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Materials of Engineering Construction

Civil Engr -8B. Professor C. T. Wiskocil.

Assignment	Subject
16	Physical Properties of Mortar and Concrete
17	Permeability and Durability of Concrete. (Portland Cement Products)
18	Metals and Their Ores. (Reduction of Iron from Its Ores)
19	Manufacture of Wrought Iron and Steel
20	Manufacture of Steel Shapes
21	Formation and Structure of Alloys
22	Constitution of Iron and Steel
23	Properties of Wrought Iron. (Properties of Steel)
24	Effects of Heat Treatment of Steel
25	Effects of Mechanical Work on Steel. (Effects of Temperature on Mechanical Properties of Metals)
26	Alloy Steels
27	Cast Iron and Malleable Cast Iron
28	Non-ferrous Metals and Alloys
29	Fatigue of Metals
30	The Corrosion of Metals

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Materials of Engineering Construction

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Assignment 1

MECHANICS OF MATERIALS

Reading assignment:- Johnson's Materials of Construction, Chapter I, pages 1-48.

Preliminary:- Before studying the various materials it is advisable to have a general knowledge of the effects of stress and deformation. The subject of internal forces and deformations is ordinarily called MECHANICS OF MATERIALS. Chapter I is a condensed treatment of this subject which is a complete course of study in itself. The assignment, therefore, will not be studied intensively. Only that information which is necessary for a thorough understanding of the properties of the materials to be studied later will be discussed. The directions "study" in these notes means that you should know the contents of the immediate subject and be able to state in your own words what you have studied. Do this with each paragraph.

Study Article 1 in connection with the following notes:

Stress;- Stress is the force at a point or plane in a body or the force between contiguous surfaces of two bodies. The forces or loads producing the stresses, or the stresses themselves, may be represented by arrows and the bodies acted upon by small rectangles. Thus in Figure 1 the weight is suspended from the support by the rod as shown. The situation could be illustrated as in Figure 2, the arrows

indicating the forces and the directions in which they act upon the body. If the weight is 100 lb. the total stress in the rod on the Section A -- A is 100 lb. irrespective of the size of the rod. Plane sections are always taken.

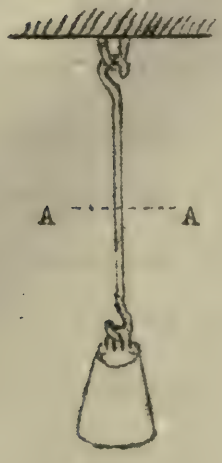
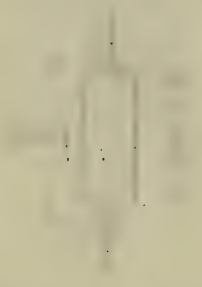


Figure 1.

Figure 2.

Unit Stress. Unit stress or intensity of stress is obtained by dividing the total stress by the entire area of the section on which it acts or over which it is distributed. Intensity of stress $S = \frac{P}{A}$ where P is the stress and A is the area. In mechanics it is usually measured in pounds per square inch, which is abbreviated lb. per sq. in., lb./ $in.^2$, or $\#/\square"$. S is the actual intensity of stress only when the stress is uniform over the section. In the case of a varying stress, S is the average intensity of stress.

Example - A body is subjected to a force of 1,000 lb. Its dimensions normal to the direction of the force are 1" by 2". What is the intensity of stress?



divided by the length which is $\tan \phi$; this is also an abstract number.

The following notes explain Article 2 which should be carefully studied.

Kinds of Stresses;- Two classes of stresses are usually considered: (a) simple or uni-directional stresses and (b) combined or bi-directional stresses. The simple stresses are tension, compression, and shear which includes simple torsion. The combined stresses are tension with tension or compression, compression with compression, and shear (torsion) with tension or compression.

Tension

A body subjected to an axial pull is in tension. The forces act in the same line and away from each other tending to pull the body apart. The section on which the forces act is taken perpendicular to the direction of the force, as A -- A in Figure 1, which shows a rod in tension. Examples of bodies in tension are; tie rods, guy wires, belts, and violin strings.

Compression

When axial forces act in the same line and toward each other the body is in compression. The section is taken as in the case of tension. Figure 4 represents a body in compression. Examples of bodies in compression are; posts supporting floors or other loads, table legs and connecting rods in single-acting internal combustion engines.

Shear

When the forces act in parallel lines either toward or away from each other, but sufficiently close so that there is no bending, the body is in shear. The section is taken parallel to the forces (note that this is different than in the case of tension and compression). Shear is illustrated best by the stress in a bolt or rivet holding two plates from sliding on each other as in figure 6.

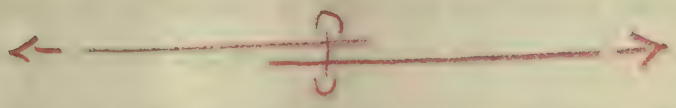


Figure 6

The particles in a body under a twisting moment or torsion, as a shaft transmitting power, have a tendency to slip on each other; the stress produced is simple shear. Simple torsion rarely occurs, it is usually combined with tension or compression.

Combined Stresses

Flexure is classed under combined stress. In simple flexure or bending the fibers on the concave side of the body are shortened and are therefore in compression whereas on the convex side, they are lengthened and are in tension. The stresses across the body vary from tension to compression; at some point between these extremes the stress is zero - neither tension nor compression. Flexure is usually produced by transverse loads which produce shear in addition to the stresses of simple bending. A loaded beam is an example of flexure. A body may be subjected to flexure and axial stress. This combination of simple stresses is illustrated in the rafters of

an A-frame roof. Shear (torsion) may be combined with compression as in the case of a shaft of a vertical turbine. Shear may also be combined with flexure as in a line shaft with power taken off by belts between the hangers or bearings.

Loads:- The ability of materials to sustain loads depends upon the manner in which they are applied. Loads may be classified as static and dynamic. Static loads include dead loads, which are sometimes called stationary or permanent loads, and gradually applied loads, as in the case of a testing machine where the load varies from zero to a maximum, during the period of the test. Dynamic or suddenly-applied loads may be applied with or without shock or impact. They may be applied occasionally or continuously. In the latter case they would be called alternating or repeated loads, depending upon whether the stress changed in character or was simply reapplied in the same manner. In either case their effect would be discussed under the subject of FATIGUE.

Elastic and Plastic Bodies:- Study Article 3. Materials may be classified as brittle and ductile. Both classes are described in this article. The term, ultimate strength, is also defined. Frequently the maximum unit stress carried by a material is simply called its strength; ultimate strength is always meant. It should be understood that the kind of stress must be specified because a material may have different tensile and compressive strengths.

Modulus of Elasticity:- Study Article 4, as it is very important. Remember that the modulus of elasticity is always denoted by E

and that although it is a ratio of unit stress to unit deformation it is measured in lb. per sq. in. because

$$E = \frac{\frac{P}{A}}{\frac{\Delta L}{L}} = \frac{\text{lb. per sq. in.}}{\text{in. per in.}} = \text{lb. per sq. in.}$$ since

the denominator is unity. E is the measure of the stiffness or flexibility of a material. Fortunately the modulus of elasticity of all kinds of steel is very nearly the same, namely 30,000,000 lb. per sq. in. E for concrete is about 1/15 that of steel, or 2,000,000 lb. per sq. in. and for wood it is about 1,500,000 lb. per sq. in.

Poisson's Ratio:- This ratio (pronounced pwà sônz') is about - 1/4 for steel and about - 1/8 for concrete. The negative sign indicates that it is opposite in character to the principal deformation. As explained in Article 5, it is the ratio of lateral to longitudinal deformation. If a block of steel is compressed its increase in width, measured perpendicular to the direction of the applied force, will be about 1/4 of its decrease in length. These relations hold only within the elastic limit of the material and the changes are very small, requiring delicate instruments to measure the amount of deformation. Poisson's Ratio is of importance in theoretic discussions in MECHANICS OF MATERIALS, and of practical importance in the manufacture of guns.

Volumetric Deformation:- Article 6 is not important. It is interesting to note, however, that a body subjected to tension will

slightly increase in volume. For example, a piece of steel 4" by 4" by 60" under a tension of 430,000 lb. will increase about 0.29 cubic inches in volume or about three hundredths of one per cent.

Shearing Modulus of Elasticity:- Shearing modulus of elasticity is explained in Article 7. It is sometimes called the modulus of rigidity and is measured in lb. per sq. in. For steel it is about 2/5 of E.

General Properties of Materials:- Study Article 8. The general properties described in this article are important and will be referred to during the discussion of the various materials.

Strength is obviously a property that materials must possess so as not to rupture or fail under stress. Frequently strength is the principal consideration, as in chains, crowbars, stern-frames of ships, and cranes. In other cases strength is of secondary importance and some other property, such as stiffness, governs the selection of the material. Wood because of its low degree of stiffness will yield under impact and for that reason (besides its light weight) it is used by some manufacturers in the construction of automobile frames. It also makes the best railroad ties for the same reason. In other machines and structures stiffness is the prime requisite.

Ductility and Malleability are closely allied. Toughness and brittleness are antonyms. Toughness is the ability to withstand impact stresses. It is dependent upon both strength and deformation. Two bodies having the same strength, as ordinarily determined, can

have different lengths providing their areas are the same. If these two bodies of the same area are subjected to impact the longer one will withstand the greatest shock. With the same cross-sectional area the toughness increases in direct proportion with the length. For most materials the energy of rupture, which is the area under the stress-deformation curve, is an index of the toughness (see the third papagraph, which begins about the middle of page 42, of Article 37). The longer piece will undergo greater deformation and will therefore have a greater area under the curve even though the maximum strength is the same as the shorter piece. In Figure 3 page 8, the steel having a tensile strength of 75,000 lb. per sq. in. is tougher than the 105,000 lb. per sq. in. steel. That is, it has a greater resistance to rupture under impact. As shown in Figure 4, on page 9, the 105,000 lb. per sq. in. steel has a higher elastic resistance to impact. It will withstand permanent distortion under greater impact stresses than the steel having a strength of 75,000 lb. per sq. in., because it has a greater proportional or elastic limit and consequently a greater area under that part of the stress-deformation curve. Material with a high elastic limit is used for springs while material with less strength but more ductility is used for machine parts subject to occasional heavy impact such as car couplings are. Elasticity and plasticity were defined in Article 3.

Uniformity of properties is very desirable. Some materials such as steel can be produced with a high degree of uniformity, whereas the properties of wood vary over wide limits.

Durability is probably one of the most important properties and, for permanent construction, it must always be considered because certain materials are very susceptible to decay or deterioration. Destructive agencies such as corrosion, bacteria, fungi, electrolysis, mechanical wear, chemical action, and fire act on materials used in engineering construction.

Materials under tensile stress:- Study Articles 11 to 16 very carefully. The stress-deformation diagram is important. Read Article 111 and see Figure 12 on page 476 and Figure 9 on page 620 for typical examples of stress-deformation diagrams. Note that the ultimate strength is obtained by dividing the maximum stress by the original cross-sectional area.

Read the following in connection with your study of Article 11.

Significance of elastic limit:- The elastic limit of a ductile material, when used in machines or machine parts which cannot be distorted, is practically its ultimate strength in both tension and compression. Very small permanent distortion will cause serious damage to machines of precision. A brittle material has no well defined elastic limit when that term is used to include the yield point, and its ultimate strength is the most reliable criterion of strength for static loads. Brittle materials are not used in direct tension or where they would be subjected to shock or impact stresses.

Materials under compressive stress:- Study Articles 17, 18, and that part of 19 which is given on page 14. Read over the rest of the

article. Remember that short blocks of brittle materials under compression fail in shear on a plane of rupture which has an angle of about 35 degrees with the direction of the compressive force. Read Article 20. Study Article 21 up to Euler's Formula.

Materials under shearing stress:- The nature of shearing stresses have been described. Read Article 23 up to equation 16 and study the last paragraph in Article 24 on page 24.

Materials under cross-bending stress:- Study the first paragraph of Article 25 and read the rest of the article. Read Article 26. Study Article 27, omiting the last paragraph.

Formula 20 on page 25 may be written $S = \frac{Mc}{I}$ where S is the modulus of rupture. This is an important quantity. It is the nominal fiber stress at a definite point, that of greatest stress. Remember that the stress varies across the section of a beam. Modulus of rupture is measured in lb. per sq. in. and may be tension or compression. M is the moment in inch pounds, c is the distance from the neutral surface to the extreme fiber in inches, and I is the moment of inertia of the section, about the neutral axis, in inches to the fourth power. Therefore $S = \frac{\text{in. lb. x in.}}{\text{in}^4} =$ lb. per sq. in. Modulus of rupture is not the actual stress because it is used with the ultimate value of M whereas the formula was developed on the assumption that the elastic limit was not exceeded. It is sufficient to remember that the actual stress is less than the modulus of rupture. Modulus of rupture is easily computed and is always given as the cross-breaking or transverse strength of material in question. Study Article 28, omiting the derivation of the

intensity of shearing stress, and the last two paragraphs. Remember that wooden beams must be inventigated for horizontal shear. This is sometimes called longitudinal shear. Omit Articles 29 to 32 inclusive.

Resilience:- Under this subject study only Article 33 and the third paragraph of Article 37, omiting the remainder of the chapter.

Reference Books on Mechanics of Materials.

Elementary texts:

Kottcamp, J. P. STRENGTH OF MATERIALS, Wiley and Sons, 1910.

Murdock, H. E., STRENGTH OF MATERIALS, Wiley and Sons, 1914.

Smith, H. E., STRENGTH OF MATERIALS, Wiley and Sons, 1914.

Slocum S. E., RESISTANCE OF MATERIALS, Ginn and Co., 1914.

More comprehensive texts:

Boyd, J. E., STRENGTH OF MATERIALS, McGraw - Hill, 1917.

Fuller and Johnson, APPLIED MECHANICS Vol. II, Wiley and Sons 1919.

Merriman, MECHANICS OF MATERIALS, Wiley and Sons, 1915.

Morely, STRENGTH OF MATERIALS, Longmans, Green & Co, London, 1915.

Answer all questions submitted to you as clearly as possible. Do not go into detail unless details are requested, but do not fail to answer all parts of each question completely. Arrange your answers neatly. Use a typewriter if available.

1. Define intensity of stress, unit deformation, modulus of rupture and modulus of elasticity. Note: Always give the units in which the quantities are measured.

2. Define stiffness, toughness, and ductility.

3. Can stiffness be measured quantitatively? (If no other information is given always answer a question of this type as completely as possible, not simply by yes or no.)

4. The diagram on page 10, in the text, was obtained from an actual test in which the load was applied continuously increasing from zero to its maximum value as indicated. Was the so-called elastic limit determined? (Do not read the description to answer this question, you should know the answer if you have studied the assignment.) Why is the point indicated the most probable value of the elastic limit?

5. What is the unit stress in a rod having an area of 1/2 sq. in. when subjected to a stress of 8,000 lb.? Ans. 16,000 lb.

6. What is the allowable pull on a 1" diameter steel bolt if the allowable intensity of stress is 16,000 lb. per sq. in.?
Ans. 12,600 lb.

7. The head of a 1" diameter bolt is 5/8" thick. When the bolt is subjected to a pull of 15,000 lb. what is the unit shearing

stress tending to strip the head from the bolt? [Ans. 7,600 lb. per sq. in.

8. Would the chattering of a machine tool (caused by bending of the tool) be diminished by making it of stronger steel?

9. Which bolt - one left full size or one turned down to the diameter at the base of the threads - will sustain the greatest impact loading?

10. Name the kinds of stress developed in: (a) an inflated tire casing, (b) the connecting rod of a double acting pump, (c) a key in an axle shaft, (d) stud bolts holding on a man-hole in a pressure tank.

11. Prepare a list of structures or machines in which the various properties listed below govern the selection of the material to be used:

(a) Strength
(b) Stiffness
(c) Flexibility
(d) Toughness
(e) Hardness.

12. Prepare a list of structures or machines which are liable to occasional overloading.

13. Name several structures or machines that could be made of brittle materials.

14. What kind of stress exists at the neutral surface of a loaded beam?

15. What kind of stress exists in the fibers on the leeward side of a flag pole bent by the wind?

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Correspondence Courses

Materials of Engineering Construction

Civil Engr. 8. Professor C. T. Wiskocil

Assignment 2.

MACHINES AND APPLIANCES FOR TESTING

Reading assignment:- Johnson's Materials of Construction, Chapter II, pages 49-96.

Preliminary:- In a comprehensive study of the important materials of engineering construction, such as we are making, it is desirable to have a knowledge of the machines and appliances used in determining the various properties such as strength, elasticity, and toughness. If properly studied, this chapter will give you the necessary information without an actual inspection of a testing laboratory. There are testing machines in the San Francisco Bay region, Los Angeles, Sacramento and Fresno - possibly in other California cities. Make an effort to witness an actual test performance. If you should visit a laboratory do not expect to see all the machines and appliances described in this assignment. Probably no laboratory in the country, not even the one in the Bureau of Standards at Washington, D.C., contains all of them.

T E S T I N G M A C H I N E S

The discussion of testing machines constitutes the first part of the assignment. A testing machine is defined in Article 42; in general, it must provide means for (a) applying the load (b) measuring the load and (c) holding the test specimen. A testing

machine is not necessarily a costly device like those illustrated in the text book; it may be a simple wooden lever arrangement with the load, a bucket of sand at the end of the long lever, such as is used in the field testing of drain tiles. Testing machines vary in capacity from the 10,000,000 lb. machine shown on page 56 to small tension machines for testing fabric, or briquette-testing machines like the ones shown on page 396. There are also various types of machines which will now be discussed in detail. In general all testing machines must be both accurate and sensitive.

Universal Testing Machines

Classes of universal testing machines:- Study Article 43. Universal testing machines may be divided into two classes, (a) vertical and (b) horizontal. Both of these classes may be divided into two groups based upon the method of applying the load; namely, screw-gear and hydraulic. Hydraulic machines may be either plain or of the Emery type. As a class universal machines are in most general use in the United States, probably because of their adaptibility. They are mostly the vertical screw-gear type either of Olsen or Riehle make, both of which will be described later. Weighing devices used in testing machines are levers, gages, and manometers. The Olsen and Riehle machines use the lever system.

The advantage of the horizontal machine, besides the one given on page 50 in Article 43, is the ease with which large specimens can be put in place. The principal disadvantage, as indicated, is the bending of the specimen due to its own weight, It also takes up a large amount of floor space.

General conditions which should be obtained in universal machines:- The principal requirements are accuracy and sensitiveness. Accuracy is insured as indicated in paragraph 1, the second sentence in paragraph 2 and the first sentence in paragraph 3 or Article 44. Paragraphs 1 and 6 of this article refer to sensitiveness. The last sentence of paragraph 7 and paragraph 10, with those already given, are the important ones of the article.

Olsen testing machines:- Study Article 45. The essential parts of the Olsen machine are shown in Figure 1. These are usually four and three-screw machines. The screws referred to are the main ones which move the cross-head. In this machine the screws do not rotate on their axes, but move the cross head to which they are attached by the axial motion given to them by the rotation of the geared nuts through which they pass. The geared nuts bear against the frame of the machine. The weighing mechanism is shown diagramatically in Figure 3. Note that when the scale beam is in balance the position of the poise-weight indicates the amount of the load. It resembles the usual Fairbanks platform scale. The purpose of the counter-weight is to counteract the unbalanced weight of the various levers in the system.

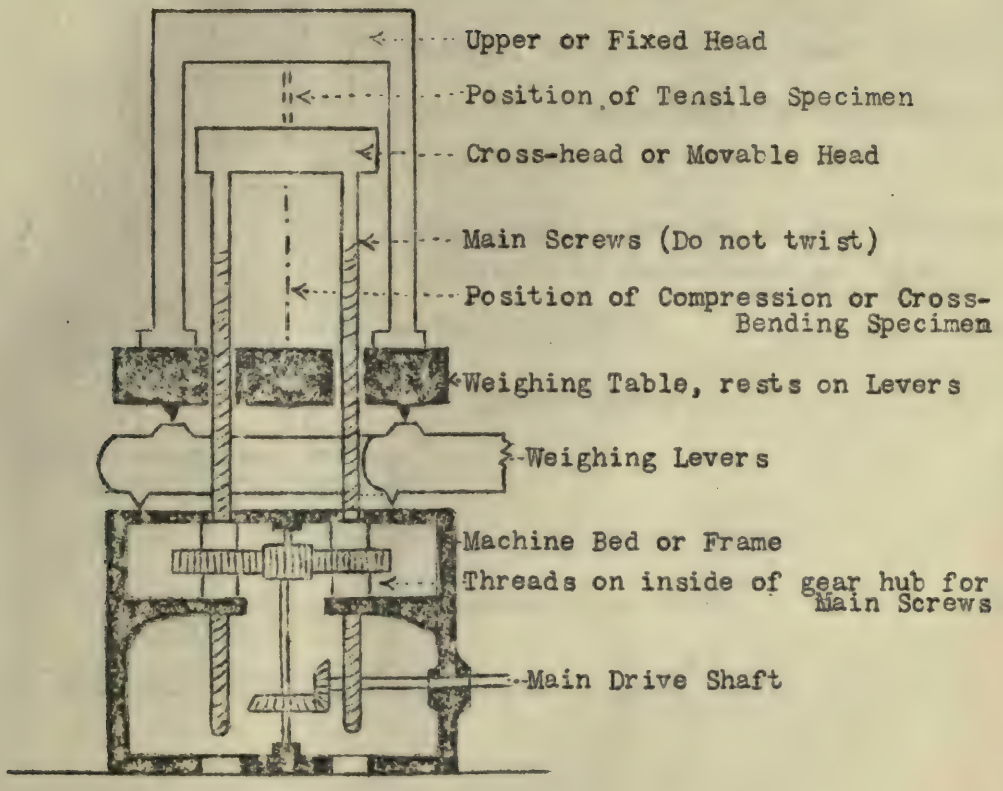
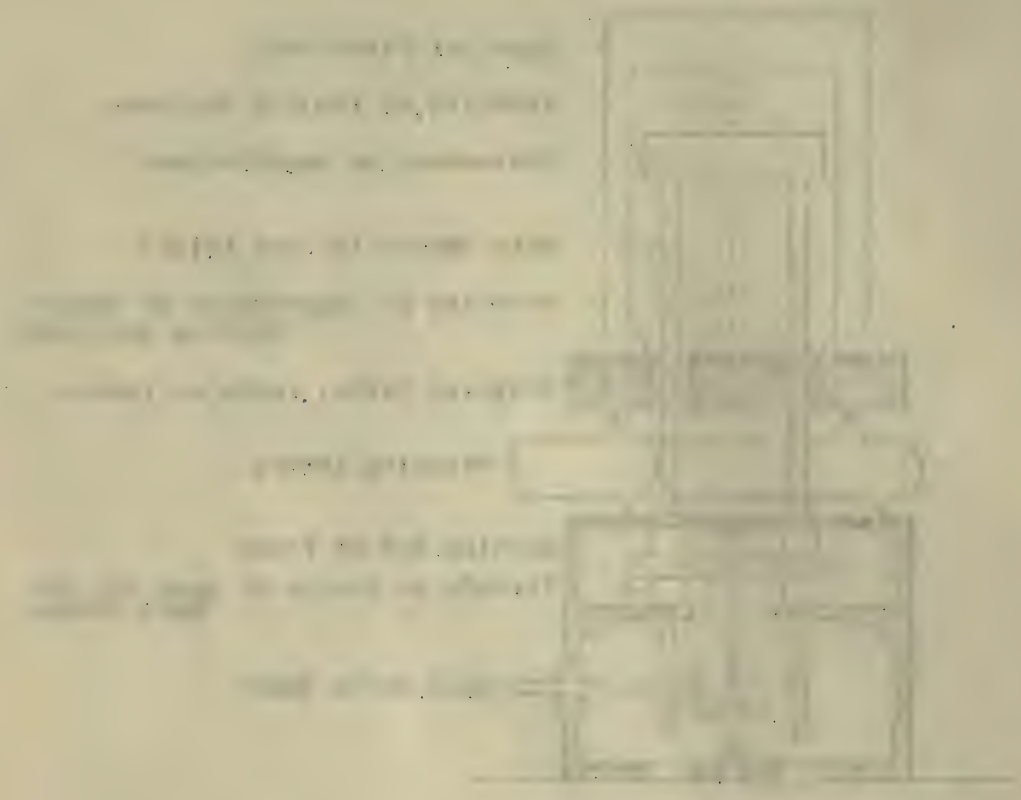

Upper or Fixed Head
Position of Tensile Specimen
Cross-head or Movable Head
Main Screws (Do not twist)
Position of Compression or Cross-Bending Specimen
Weighing Table, rests on Levers
Weighing Levers
Machine Bed or Frame
Threads on inside of gear hub for Main Screws
Main Drive Shaft

Figure 1.



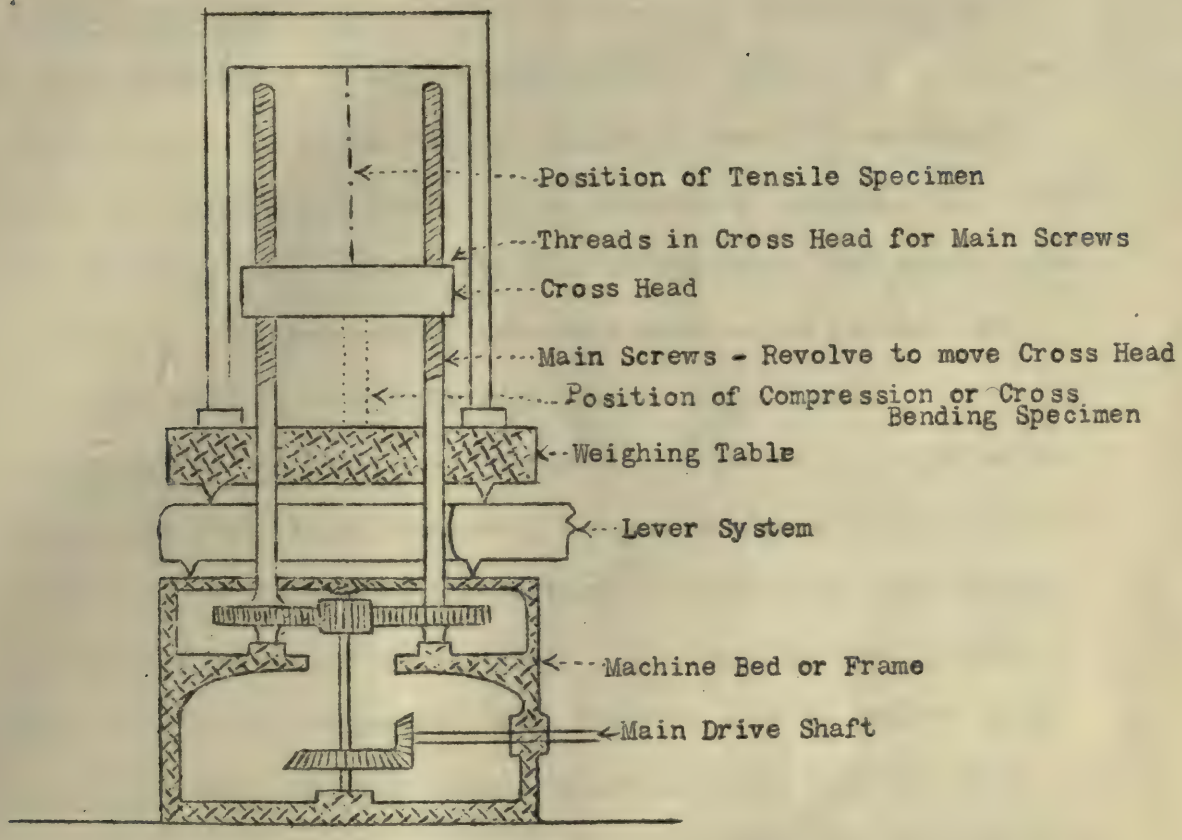

Position of Tensile Specimen
Threads in Cross Head for Main Screws
Cross Head
Main Screws - Revolve to move Cross Head
Position of Compression or Cross Bending Specimen
Weighing Table
Lever System
Machine Bed or Frame
Main Drive Shaft

Figure 2

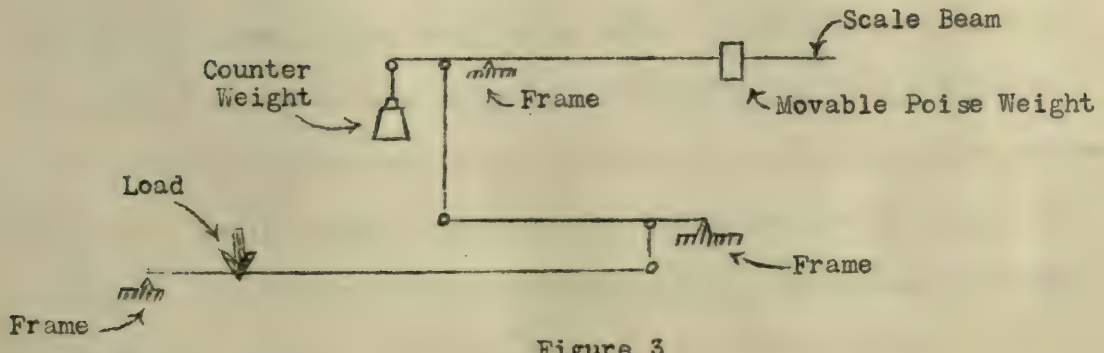
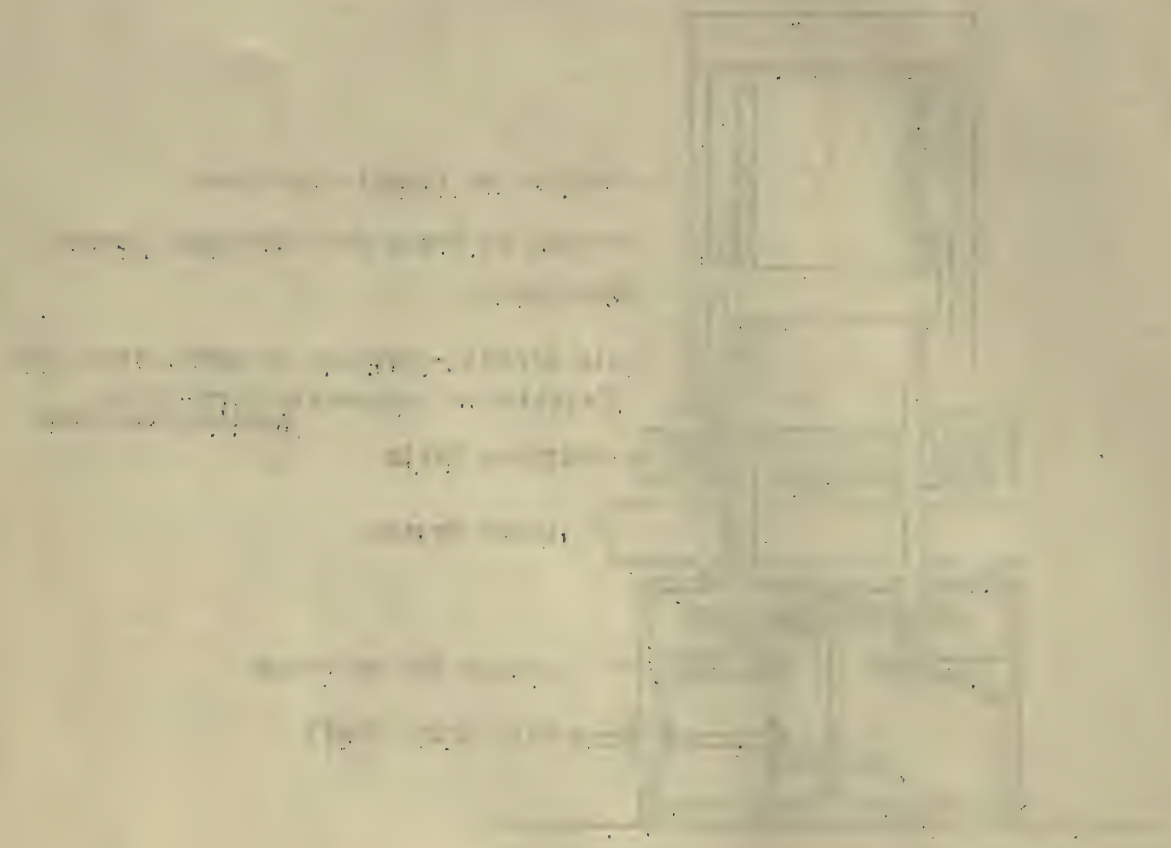


Figure 3



Riehle testing machines:- Study Article 46, It describes the Riehle (pronounced rē' lāy) testing machine. This is the principal competitor of the Olsen machine. Figure 2 shows the essential parts of the Riehle machine. It is a two-screw machine. The cross-head is threaded to receive the main screws which revolve and cause it to move. The main screws revolve without axial motion. The weighing mechanism is of the same design as the Olsen.

The Emery testing machine:- Study Article 47 and Figure 4 in the text. The wide range in capacity and sensitiveness of this type of machine is illustrated by the footnote on page 54. A high degree of accuracy is not always necessary. The Emery machine is made to order and is very expensive. Note that the load is applied to one end of the specimen by the usual hydraulic press which can have friction of any amount or variation without affecting the load which is measured at the other end of the specimen by the pressure in a completely closed chamber. There are two of these chambers or capsules, one to take the full load on the specimen and another, of smaller size, connected to it by hollow tubing. The smaller capsule actuates a lever system similar to Figure 3 (in the notes) which measures the load on the capsule. The liquid in the capsules is incompressible, therefore there is no friction. The diaphrams have only very small exposed surfaces and can therefore be made of thin material. In the Emery weighing levers the fulcra consist of thin plates (in tension), whereas in the Olsen and Riehle levers, the fulcra are knife edges (in compression). The Emery lever system is the more sensitive.

Tension Testing Machines

This type is not mentioned in the text book but there are machines which will test only in tension. In construction and operation they are similar to the Olsen and Riehle universal testing machines. A machine for testing briquettes in tension is shown on page 396. Materials frequently tested in tension are wire, various kinds of fabric, leather and paper.

Compression Testing Machines

Study Articles 48 and 49, Read Article 50, remember that the largest machine has a capacity of ten million pounds in compression only. It is a hydraulic machine and the screws (shown in Figure 6 in the text, page 56) are merely for changing the position of the cross-head.

Transverse Testing Machines

Beams of wood, concrete, and steel are tested in this type of machine. Study article 51 and Figure 9 together with the text referring to it on the middle of page 59. Read Article 52. In the cross-bending test of cast iron which is made on the machine illustrated in Figure 9, page 59, the bending moment is a maximum under the load. The span is usually 12 inches. The other type of transverse loading is illustrated on page 202, Figure 2, It is known as the third point loading, the beam being divided into three parts, usually equal. Equal loads are applied at equal distances from the ends of the beam. The bending moment between the loads is constant and the shear is zero. This is a more desirable condition than that obtained by the center loading.

Cold-Bend Testing Machines

Read Articles 54 and 55. The cold bend test is usually used for various kinds of steel, both rolled and cast. The bend test is a very important one for steel to be used for reinforced-concrete.

Torsion Testing Machines

The torsion test is most satisfactory for testing the shearing strength and elasticity of ductile materials. Torsion cannot be put on a specimen in a machine of the universal type, it takes a special form of machine such as shown in Figure 15 page 63. Torsion test specimens are usually circular in section, either hollow or solid. Read Article 57.

Impact Testing Machines

The impact test is used to determine the amount of energy (measured in foot-pounds or inch-pounds) necessary to stress a specimen up to its elastic limit or to rupture it. The machine shown in Figure 19, page 66 is used by the United States Forest Service to test the toughness of wood. The usual impact test is in flexure but impact compression and tension tests can be made in the Turner machine. The pendulum type of impact testing machine subjects the specimen to flexural stresses; it can be arranged to test a specimen in tension. If ductile materials are tested in impact-flexure the specimen is usually notched so as to localize the stress and insure failure. Study Articles 58, 59, and 60 in the text.

Endurance Testing Machines

Endurance or repeated stress testing machines in common use are of two general types. The Upton-Lewis machine (not shown in the text) and the Kommers machine (shown in Figure 26, page 72) produce flexural stresses by simple bending of the specimen, where-

as the White-Souther machine produces flexural stresses by rotating a loaded specimen (The machine is shown in Figure 25, page 71). In both types of machines there is a reversal of stress (from tension to compression) as the specimen is bent or rotated. The Upton-Lewis machine works best at stresses above the elastic limit. Read Articles 64 and 66 and study article 65.

Hardness Testing Machines

Hardness testers could not be classed as testing machines if the definition previously given were strictly interpreted. They are commonly called testing machines and will, therefore, be discussed under this heading.

Filing, cutting, and scratch tests have been proposed to test hardness, but the indentation method has come into the most general use. The Brinell machine and the Scleroscope represent machines using the indentation method. Read Article 61 and study Articles 62 and 63.

AUXILIARY APPLIANCES EMPLOYED IN LOADING SPECIMENS

In tension and compression tests it is essential to have the load applied axially and uniformly over the cross-section of the test specimen.

Devices For Tension Tests

Study Articles 68, 69, and read Article 70. If carefully used the devices shown will give satisfactory results. None of them give absolutely uniform distribution of stress.

Devices For Direct Shear Tests

Study Article 56 with Figures 13 and 14 which are given

under testing machines in the text. These devices give the approximete shearing strength of the material tested, because it is impossible to make the test without producing some bending or compressive stresses in the test specimen.

Loading Appliances for Compression Tests

Study Articles 71 to 74 inclusive. For ease in testing, the spherical-bearing block should be placed on top of the specimen. The radius of the block, r_1 in Figure 32, page 76, should be equal to r, the radius of the specimen tested.

Bedments

It is essential to have flat surfaces on the ends of compression test specimens. If possible the use of bedments should be avoided. If a flat surface cannot be secured plaster of Paris is used. Porous surfaces should be shellaced before being capped with plaster of Paris. A satisfactory surface can be secured by pressing out the excess plaster on a smooth, plane surface of glass or metal. The resulting bedment should not exceed 1/8" in thickness. Plaster of Paris bedments should be allowed to set (about five hours) before testing the specimen. Study Articles 75 to 78 inclusive.

Deformeters

An instrument used to measure the change in length of a specimen tested in tension is called an extensometer; if used in a compression test, it is called a compressometer. Any device for measuring the amount of bending of a beam is a deflectometer, whereas a troptometer is used to measure the amount of twist in a torsion test.

Extensometers:- Study the first paragraph and those marked 1, 2 and 3 of Article 79, Article 80 and the last paragraph of Article 82 which describes the Berry Strain-Gage. Read Articles 81, 83 and 84. Note that the Berry Strain-Gage could be used as a compressometer. It requires very careful manipulation to get accurate results.

Compressometers:- Study Articles 85 and 86. The instrument shown in Figure 46, page 87, is frequently made with a stiff rod instead of wires to actuate the pointer on the dial. The rod is attached to one ring and bears on the roller of a dial on the other ring. Two dials would be required if rods were used in the compressometer shown. Read Articles 91 and 92. These articles describe special applications of compressometers and extensometers.

Deflectometers:- Study Articles 87 and 90, read Articles 88 and 89.

Troptometers:- Read Articles 93 and 94.

Miscellaneous devices:- Read Articles 95 and 97. Omit Article 96.

Answer the following questions:

1. What is a testing machine?
2. What is a universal testing machine?
3. Describe the mechanism for applying the load to the test specimen in a testing machine of the screw-gear type.
4. Describe the weighing mechanism of a screw-gear testing machine.
5. Make a diagramatic sketch of the weighing system of a screw-gear testing machine
6. What are the advantages, disadvantages, and limitations of (a) screw-gear, (b) hydraulic, and (c) Emery types of testing machines?
7. Describe the essential part of the Emery testing machine.
8. Name the various types of impact testing machines.
9. What are the advantages and disadvantages of the vertical and horizontal types of universal testing machines?
10. What are the essential requirements for (a) a universal testing machine (b) an impact testing machine?
11. Name the types of hardness testing machines.
12. Describe a scleroscope.
13. Briefly describe the various types of endurance or repeated-stress testing machines.
14. In what units are the test results of (a) Turner and (b) Russell machines measured?
15. What kind of a machine would you use to determine the shearing modulus of elasticity of a material?

16. In what kind of tests are spherical bearing blocks used? Why are they used?
17. What is the purpose of a bedment?
18. Can the use of bedments be avoided?
19. Name the various types of deformeters.
20. Describe a Berry Strain-Gage.
21. What are the advantages and disadvantages of the Berry Strain-Gage?
22. What are the essential requirements for extensometers?
23. Make a diagramatic sketch and describe a micrometer-screw electric-contact extensometer.
24. What is a troptometer?

UNIVERSITY OF CALIFORNIA EXTENSION DIVISION

Correspondence Courses

Materials of Engineering Construction

Civil Engr-8. Professor C. T. Wiskocil

Assignment 3.

TESTING OF STRUCTURAL MATERIALS

Reading assignment:- Johnson's Materials of Construction, Chapter III, pages 97 to 139.

Preliminary:- The foundation for a comprehensive study of the Materials of Engineering Construction will be completed with this assignment. The information is closely related to the study of the materials themselves and will possibly be found more interesting than the first two assignments.

Most of the properties of materials have been determined by mechanical tests. Materials whose properties are not well known will be tested according to present standards or by methods to be devised and perfected by research testing which is conducted for the purpose of determining the proper size of test specimen, the effect of methods of procedure on the test results, and similar questions.

The results of mechanical tests are reliable criteria for the acceptance or the rejection of structural materials. Mechanical tests for quality and conformity to specifications, chemical analyses, and microscopic examinations are used in commercial testing. Examinations for surface defects, surface finish, correctness of dimensions, and the supervision of manufacture to insure adherence to predetermined methods are called inspection.

General observations:- Study Article 98. The article emphasizes the fact that test results are, in most instances, affected by the methods by which they were obtained. For this reason it is necessary to standardize methods of procedure in order that results secured under such conditions may have relative value at least. The selection of standard methods should be made with reference to the practical use of the material. Materials and finished products are tested under a wide variety of standards which frequently, in certain tests, show exact agreement. Some of the standards in common use are: American Society for Testing Materials, Society of Automotive Engineers, United States Bureau of Standards, United States Navy Department, International Aircraft Standards, and those of Lloyds of England.

Mechanical tests classified:- Study Article 99. Static tests yield most of the published test results. Dynamic and wearing tests are very important but have not yet been thoroughly standardized. Accelerated weathering tests have not proved satisfactory. Nevertheless such tests would supply very important information. Structural tests are not so well standardized as specimen tests; frequently, however, acceptance depends entirely upon structural tests. Full-size forms are not always tested to failure; anchors, for instance, are only subjected to proof-loads.

THE ACCURACY OF MACHINES AND APPARATUS

Methods of determining the accuracy and sensitiveness of testing machines:- Study Article 100. Testing machines should be calibrated when installed and if the machine is in constant use the cali-

bration should be checked at regular intervals. The calibrated tension bar or compression prism can be made of such size as to load the machine to be calibrated up to its full capacity. This produces large deformation and increases the relative accuracy of the determination. Furthermore the apparatus is portable. This is a desirable feature since few owners of testing machines have means of calibrating them and must therefore call upon outside assistance. The cost of such assistance would be greatly increased if standard weights had to be shipped for each calibration.

The so-called standard bar has a known modulus of elasticity (which was obtained in a machine of known accuracy or one whose accuracy was determined by standard weights). Its cross-sectional area and the gage length, length over which the deformation is measured, are also known. The actual load producing any measured deformation can be readily computed.

This computed load is then compared with the load observed on the scale-beam of the machine. The difference between the loads, divided by the actual or true load is the percentage error in the machine. Its sign, indicating whether the machine reads high or low, should always be given. In a well-designed machine the percentage error is constant over its entire range. The extensometer must be permanently attached to the standard bar.

The calibration of apparatus for measuring deformations:- Read Article 101. It is not necessary that measuring apparatus be correct. The errors, however, must be known and they should pre-

ferably be constant or should change at a constant rate. For any important test or investigation all apparatus, including machines and instruments, should be calibrated. If in error, the required corrections must be applied to the observed measurements.

SELECTION AND PREPARATION OF SPECIMENS

Selection of specimens:- Study Article 102. The proper selection of samples is of great importance. Careless or improper sampling is one of the most serious sources of trouble in commercial testing.

The preparation of the specimen:- Study Article 103. It has been known for a long time that the size, shape and method of preparation of the test specimen affect the test results. The effect of these controlable variables is studied in research testing which is being carried on in government, industrial, and educational laboratories.

TENSION TESTS

Tension tests are universally used to specify the properties of ductile materials. They are so generally used because they give the elastic limit strength, ductility, and toughness besides the tensile strength and modulus of elasticity. When the strength of a material is spoken of it is generally understood to mean the maximum tensile strength. The best practice is, however, to specify the particular strength meant. Brittle matterials, namely cast iron and cementing materials, are tested in tension.

Only the ultimate tensile strength of these materials

is obtained. Cements are tested in tension, because the machine for such tests is much cheaper than a compression machine and the specimens are more easily prepared and tested. Tension tests are gradually giving way to the compression test, because cement and mortar, which are brittle materials, are generally used in compression.

Study Articles 104, 105, the first and last paragraphs and the text under Figure 2 on page 106 in Article 106.

Read Article 107. The essential points to remember are: The average diameter or dimensions are determined and the gage length then laid off (usually 2" or 8"). The gage length is not divided into equal spaces as indicated in the text. The speed of testing should be such that the scale-beam can be kept in balance so that the phenomena of yield point and maximum can be accurately determined. The properties of soft steel do not seem to be effected by speeds up to six inches per minute.

Study Article 108, 109, 110 and 111. See the typical stress-deformation curves on pages 210, 256, 476 and 601. The drop of the scale-beam indicates the yield point in the commercial tension test of medium carbon steel or any material having a decided yield point. The load is applied continuously and the scale-beam is kept balanced. In order to keep the beam in balance the poise-weight must be advanced at a steady uniform rate, depending upon the speed at which the cross-head of the machine is moving. At the yield point the rate of increase in load is suddenly changed

and in some cases actually becomes negative (see Figure 2 page 811, diagrams for 0.37% and 0.51% carbon steels). Before the rate of motion of the poise-weight can be changed it has advanced too far and causes the beam to fall, sometimes the load actually decreases as in Figure 2 just referred to, so that the beam is out of balance. This phenomenon is known as the drop of beam.

COMPRESSION TESTS

The compression test is used chiefly for the brittle materials. Study Article 112. Read Article 113, study Figure 7 on page 114 in this article. Whereas the compression test specimens in the past have been cubes, the tendency is to increase the length of the specimen. Most concrete specimens are 6" in diameter and 12" long. Mortar specimens are 2" in diameter and 4" long while metal specimens are about 1" in diameter and 4" long. Omit Article 114.

The important facts in Article 115 are: that when the elastic limit and modulus of elasticity are determined the deformation should be measured on at least two sides and the yokes of the compressometer should be placed not less than half of the diameter from the nearest bearing surface. A spherical bearing plate should be used.

Study Articles 116 and 117.

TRANSVERSE TESTS

Study Articles 118 to 122 inclusive, omit only Table 1, page 122. The calculated stresses of tension and compression - modulus of rupture - are nominal values and are higher than the

actual stresses. Cast iron is the only material in which the size of the test piece affects the modulus of rupture. In other materials it is independent of the size of the specimen, provided, of course, that the material is the same, but depends upon the shape of the cross-section.

IMPACT TESTS

Study Articles 123 to 127 inclusive. No impact test has been accepted as a universal standard because the results are affected by both the design of the machine and the shape and size of the test specimen. A drop-test for railway rails has been standardized and adopted, see Figure 20, page 67. Lloyds Register of Shipping specifies a definite drop-test for ship anchors. The notched-bar test of the Charpy and similar pendulum machines is quite widely used in Europe but has not been adopted here.

HARDNESS TESTS

Study Articles 128 to 135 inclusive; Omit Table 2 on page 129 and the formulas in Article 134. The Brinnell machine and the Scleroscope both test the relative hardness or the uniformity in hardness of a given material. The Scleroscope is well adapted to testing the hardness of gear teeth. When a manufactured piece has given satisfactory service, its hardness may be determined; and other pieces bought later may be required to show the same degree of hardness. Hardness depends upon other properties and for any given material the hardness indirectly measures the tensile strength.

Study Articles 136 to 139 inclusive. Remember that the direct shear test will determine only the breaking strength in shear.

TORSION TESTS

Study Articles 140 to 142 inclusive. Remember that the torsional modulus of rupture, the ultimate shearing stress in torsion computed from formula 16 on page 22, is not the actual shearing strength of the material. The formula is similar to the one for extreme fiber stress in bending, the modulus of rupture. Tension is a secondary stress developed in the torsion test; for brittle materials it is less than the shearing strength and brittle materials subjected to torsion will, therefore, fail in tension. The torsion test will, however, determine the modulus of rigidity of brittle materials.

BEND TEST OF METALS

Study Articles 143 to 148 inclusive. The bend test is generally used to estimate the ductility of metals, the metal may be cold or heated. The test can be used to determine whether a given metal is ductile enough to be put through certain manufacturing processes.

DRIFTING TEST OF METALS

The drift test like the bend test gives an indication of the ductility of metals. It is used on steel plates to be fastened together by rivets because rivet holes in field joints are brought into alignment by the use of a drift pin. This operation should

not cause the metal to crack or tear. In the best grade of work rivet holes should be reamed, because drifting weakens the joint. Study Article 149.

RESUME OF CHAPTER III

Study Article 150; it is a condensed statement of the properties revealed by the tests described in the assignment and the uses made of the tests.

Answer the following questions:-

1. What should be the guiding principle in the preparation of new testing methods and the design of testing machines?

2. Make a list of structural forms, machines or machine parts which are tested as a whole or full-size.

3. Name the different ways of calibrating testing machines.

4. Describe the standard bar method of calibrating a testing machine.

5. In the method described in question 4 make a sample calculation to show how the error and the percentage error in a testing machine is calculated. Assume all necessary data.

6. What are the objects to be kept in view when selecting samples for test specimens?

7. What are the general requirements for the preparation of test specimens?

8. What is the significance of the tension test?

9. What is a commercial tension test?

10. Describe the tensile fracture of medium carbon steel.

11. How is the yield point in a tension test determined?

12. What causes the drop of beam in the tension test of medium carbon steel?

13. How is the elongation in a tension specimen distributed with reference to the point of fracture?

14. Prepare a stress-deformation diagram. Put in a curve for mild steel and show the elastic limit, the apparent elastic limit, the proportional limit and the yield point.

15. Make a list of materials usually tested in tension.

16. What information can be secured from a compression test?

17. Make a list of materials usually tested in compression.

18. How are the deformations in the transverse test measured?

19. What materials are tested in bending?

20. What is the object of the impact test?

21. Compare the Brinnell and Scleroscope methods for measuring hardness.

22. How does direct shearing stress differ from the shearing stress computed in the torsion test?

23. What information can be obtained in the torsion test?

24. How do brittle materials fail in torsion?

25. What property of materials is determined in the bend test?

26. Name materials which are tested in bending.

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Materials of Engineering Construction

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Assignment 4.

USES AND PHYSICAL PROPERTIES OF WOOD

Reading Assignment:- Johnson's Materials of Construction, Chapter IV, pages 140 - 178.

Introduction:- Wood is one of the primary materials of construction and, due to the ease with which it can be worked and its comparative light weight, it has always been used as a structural material. Wood has sufficient strength and hardness for general purposes but is inflammable and subject to decay. Its general use is therefore, confined to inexpensive or temporary construction. It is used for railroad ties chiefly because of its resilience.

Wood is an organic material. Its physical and mechanical properties are dependent upon its structure, which in turn is dependent upon life processes, age, and other physiological causes. Because of its complex cellular structure specimens of wood cut from the same stick and appearing to be identical often show marked variations in strength.

Importance of Wood:- Read Article 151. The latest estimates indicate that there is a total of 2,800 billion board feet of standing timber in the United States. (Timber is usually measured in board feet. The unit is one foot square and one inch thick or 144 cubic inches). This estimate includes only trees of sawlog size and not wood that could be used for such purposes as fuel and pulp.

It has been frequently stated that the supply of timber in the United States will be exhausted within the next thirty or forty years because the rate of annual depletion by insects, fires, and lumbering (wood cut for all purposes) is about 100 billion board feet. Remember that these are scientific estimates and the extent to which known factors will control the result cannot be exactly determined and the possibility of unknown factors must be provided for. The virgin forests of Douglas fir and southern yellow pine alone, will continue to supply satisfactory structural timber for several generations. The increasing practice of forestry will insure an increased annual growth and minimize the occurrence of fires. Three California redwood companies have announced plans for permanent forest management whereby they will work their properties so as to yield regular crops of timber and thus insure a permanent supply of raw material for their plants. Large tracts of non-agricultural land which are well suited for the production of timber could be utilized if necessary. Furthermore the more general use of preservatives and the more economical use of wood both tend to conserve the supply. The exhaustion of our forests is, therefore, problematic.

Production:- About one half the available supply of timber in the United States is in the Pacific Coast forests (Washington, Oregon, California, Idaho, and Montana). It consists principally of Douglas fir, western hemlock, sugar pine, western yellow pine, redwood, and cedar.

The annual production of timber is about forty billion board feet. Washington and Louisiana produce the most; together they supply about one fifth of the total production.

About one fifth of the wood cut annually is used in engineering construction. The following table gives the approximate distribution:

Structural timber and lumber	13 %
Ties	4
Mine timbers	2
Car construction	1
Poles	.2
Ship construction	.2

About 40 % is used for firewood and 13% for planing-mill products such as doors and window-sashes. Wood is also made into pulp, shingles, laths, furniture, posts and containers (barrels, boxes, and crates).

Wood, Timber, and Lumber:- Wood is the hard fibrous substance of trees and shrubs. It is composed of lignocellulose, which is a starch-like substance, permeated by materials known as lignin, resin, coloring-matter, water and small proportion of inorganic matter (evident as ash).

Timber is wood suitable for construction whether in the tree or cut and seasoned. When applied to cut wood the term is used to designate pieces of comparatively large breadth and width.

Lumber is timber that is sawed or split into boards, planks, or other forms of comparatively small dimensions. This term is used chiefly in the United States.

GENERAL CHARACTERISTICS OF WOOD

Structure and appearance:-Read Article 152. A knowledge of the structure of wood is important because of its relation to the mechanical properties. In general the structure is cellular, consisting of minute, hollow, elongated tubes grown together and closed at the ends. In some woods the tubes are open to permit the movement of sap. Because of its structure and composition wood can be cut easily and nails and other fastenings can be readily driven into it. The empty cells are dead air spaces and retard the conduction of heat and sound. Because of its porous nature it will take up preservatives. Paint and other surface finishes will readily adhere to its surface and thus prolong its life.

Classes of trees:- Read Article 153. The botanical classification of trees whose wood is used in construction in the United States is as follows:

I Gymnosperms
  I A Coniferae

II Angiosperms
  IIA Dicotyledons

The seeds of the gymnosperms are not enclosed in fruit. The gymnosperms are divided into three groups. Two of them grow principally in the tropics; the other one, the coniferae, is the only one that yields merchantable lumber. The pines, firs and cedars are some of the trees included in this group. The seeds are borne on a series of overlapping scales, arranged on cones. The leaves are narrow, stiff or needle-like. The trees are sometimes designated

as needle-leaf, softwood, evergreen, coniferous, and cone-bearing.

The seeds of the angiosperms are always enclosed. There are two groups of angiosperms. They differ principally in the structure of their stems or trunks. The first group, the monocotyledons, have one seed leaf or cotyledon (therefore the name mono-cotyledon). These trees, which include the palm and the bamboo, grow principally in the tropics. The second group, the dicotyledons, have two seed-leaves. This group includes the oaks, maples, and hickories, which are sometimes called broad-leaf, hardwood, or deciduous trees.

The conifers yield the largest proportion of woods used for structural purposes.

Classification of Woods:- Frequently woods instead of trees are classified. In the botanical classification of trees given in a previous paragraph the two important groups were the conifers and the dicotyledons. They grow in the same manner and their woods, therefore, are in one group sometimes called outside-growers, banded woods, or exogens. The elements of the woods in this group develop in the cambium layer which is just inside the bark of the tree. Each growing season new wood is added to the previous growth. In cross-section, these seasonal additions appear as concentric circular layers or rings. The names conifers and dicotyledons are applied to the divisions of this group. The designation soft-wood for the conifers is not logical because some of the woods of this division are actually very hard as in the case of some of the pines, while the term hardwood is incorrectly applied to the dicotyledons

basswood and chestnut whose wood is soft. The terms needle-leaf and broad-leaf are more exact but the designation conifers and dicotyledons is preferable.

The other group of woods includes the unimportant monocotyledons in which the wood elements are in separate bundles scattered throughout the tree. The cross-section of these woods has a dotted appearance. The trees grow largely by expansion of the cells already formed and do not continually increase in diameter but attain their maximum diameter early in their growth. The name endogen is sometimes given to this group; other names are inside-grower and non-banded woods. The use of the terms endogen and exogen should be avoided because engineers and botanists seldom employ them in the same way.

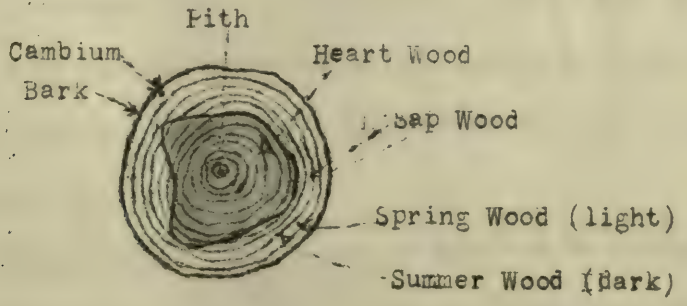
Botanical Names:- The use of botanical nomenclature obviates the confusion which occurs when trees are designated by common or local names. Thus the names of the species Pinus palustris are longleaf, yellow, hard, Georgia, and southern pine, in addition to some 25 others.

Botanical names are made up of terms which denote genus and species. Sequoia is the generic name for all species of redwoods. Sempervirens and washingtoniana are names of particular species of redwoods; the latter is the Big Tree or Mammoth Redwood.

Botanists have sometimes given different names to the same species. The abbreviated name of the person responsible for a given designation is therefore added to the complete name. An example is Sequoia sempervirens Endl.

A genus is a group of related species while a species is the smallest group of individuals to which distinctive characteristics can be assigned.

Structure of wood in general:- Read Article 154. The accompanying diagram shows the cross-section of a tree. The pith stores up plant food for the young stem and it seems to be of only temporary service. A layer of spring wood and one of summer wood constitute a so-called annual ring. Early and late growth would be better designations for the parts of the annual rings. Early growth is usually formed in the spring when the tree requires most water. The water-conducting wood-elements predominate and produce porous or less compact wood. The late growth is formed in the summer and early fall; it is heavier and denser than the early growth. Distinct periods of rapid and slow growth may be caused by wet and dry seasons which sometimes occur oftener than once a year. The number of so-called annual rings does not always give the exact age of the tree. This has been found to be the case in certain trees which were cut at a known age.



Cross Section of Tree

HEARTWOOD;- While the cell structure of heartwood is the same as that of sapwood, the protoplasm is absent and inert minerals and pigments appear. The thicker cell-walls of heartwood are probably caused by the accumulation of deposited materials. The change from sapwood to heartwood does not take place ring by ring or a little each year but may skip many years and eight or more rings may change to heartwood in one year. The change is not uniform around the tree, it may occur in one side before the other so that one ring may be part heartwood while the other part remains sapwood. (Reference - U.S. Bureau of Plant industry Bulletin No. 14 p. 15.) In most trees, however, the line of division between the heartwood and the sapwood and that between the sapwood and the bark, are concentric around the pith..

SAPWOOD:- Sapwood lies between the bark and the heartwood. It derives its name from the fact that it carries up-ward sap currents. (The descending currents pass through the inner bark)

BARK:- The bark affords protection to the tree and is an agent in its development.

CAMBIUM LAYER:- The cambium layer consists of a thin layer of small cells between the bark and the sapwood. These cells develop into the wood cells of the sapwood and form the annual rings. The outer cambium cells develop into new bark.

GRAIN OF WOOD:- Study Article 155. Wood is said to be straight grained when the direction of the wood elements is parallel with the pith. If the elements are arranged in a spiral course around the

pith, the wood is spiral grained. The grain of a small stick is influenced by the way it is cut from the log. If the lines on the surface (formed by cutting the annual layers of wood cells) run diagonally across the piece, the bending and compressive strength will be reduced. Inclination of more than 1 in 20 to the edge of the stick should not be allowed in high grade material. Spiral grain can be detected by season checks or by splitting the stick.

STRUCTURAL ELEMENTS OF WOOD:- Study Article 197. The four principal wood elements are tracheids, wood fibers, vessels, and parenchyma. The cell walls of these elements are composed of xylem (zī´ - lĕm) or wood tissue.

Tracheids are small thin-walled tubular cells which, in coniferous wood, are about 0.2 inches long and polygonal in cross-section with a diameter of about 0.002 inches. The cells with their longitudinal axis parallel with the pith of the tree, are arranged in radial rows. The thick walls of the cells formed toward the end of the season's growth reduce the size of the opening in the cells but add to the strength of the element. Tracheids have bordered pits in their side walls. These pits are small portions of the wall where the original cellulose membrane of the cambial cell has not been thickened by the addition of lignin (inert minerals). These pits allow the passage of water between adjacent cells.

Wood fibers are small thick-walled tubular cells with tapered ends rarely over 0.1 inch in length. They usually have small

simple pits. They are not found in coniferous woods, but are the principal source of hardness and toughness of broad leaved woods.

Vessels are long tubular elements with many border pits. Vessels often extend the entire length of the tree. They vary in diameter from 0.003 to 0.03 inches. They are formed by the union of original cambial cells in which the end walls become partially or wholly absorbed so that they present an unobstructed passage for water from the roots to the branches of the tree.

Parenchyma are made of thin-walled cells joined end to end. The end and side walls are of equal thickness and have many simple rounded pits. Parenchyma resemble wood fibers in shape. Their chief function is the storage and distribution of food materials.

Rays, often called medullary rays, are radial bands of cells which cross the tree at right angles to the pith. In some species the rays are composed of parenchyma, in others the cells are tracheids. The principal function of the rays is the lateral distribution of plant food.

Coniferous woods are composed principally of tracheids with rays at right angles to these cells. Resin ducts occur in the resin-bearing trees usually between the early and the late wood. These ducts have no walls of their own but are only intercellular channels with an average diameter of 0.01 inches for the larger ducts. Coniferous woods are quite uniform in cross-section and because of the absence of large vessels are called non-porous. The thick-walled cells in the late wood give that portion of each annual ring a darker color than the early wood. Study Article 198.

Broad leaved woods have a more complex structure. They consist chiefly of wood fibers with prominent medullary or pith rays of parenchyma. Broad leaved woods are ring-porous or diffuse-porous depending upon the distribution of vessels or pores. In the ring-porous woods the pores are grouped in the early wood and make a pronounced annual ring, whereas in the diffuse-porous woods, the vessels have a uniform dispersion and the annual rings are not so distinct. Study Article 199, note the statement regarding tyloses. (See Figure 2 on page 143). Omit Article 200.

DEFECTS IN TIMBER:- Study Article 156. The most common defects in timber are knots, checks, and shakes. Knots are classified as sound, loose, or decayed. They affect the compressive and transverse strength of wood, also its workability and shrinkage. Checks are caused by stresses set up in seasoning. Large structural timbers are difficult to season without checking. The outer portions dry and shrink while the inner part is still moist, thus causing the wood to split.

A shake is a separation between two annual rings.

Both checks and shakes decrease the resistance to longitudinal shear besides affecting the durability by admitting air and moisture. Poles with checks the entire length are also weak in torsion - the cross-arms twist the pole when the wires break.

Density and weight:- Study Article 158. The term specific weight means the weight of a specific or definite volume, which in this book is taken as the cubic foot. The specific weight of different

woods varies with the moisture content. With a given percentage of moisture, however, the specific weights for each species are not the same but they vary due to the structure of the wood. The amount of wood substance, then, determines the specific weight. Wood substance itself with a specific gravity of 1.55 would not float on water. A cubic foot of water weighs 62.5 pounds, a cubic foot of wood substance (not possible in natures) would weigh 1.55 times 62.5 or approximately 97 pounds. (A cubic foot of anthracite coal weighs about 97 pounds.) The following table indicates the effect of moisture on the specific weight of the species of wood listed. Air-dry wood contains from 12 to 15 % moisture while a wood with 8% moisture is said to be kiln dry. Note that the average specific weight for a given lot of wood may vary by ± 5 % from the values in the table and individual pieces may show as much as ± 20 % variation.

	Green	Air-Dry	Kiln-Dry
Blue gum (Eucalyptus globulus)	70	54	52
White oak (Quercus alba)	61	47	46
Douglas fir (Pseudotsuga taxifolia)	40	33	32
Western yellow pine (Pinus ponderosa)	53	29	28
Sugar pine (Pinus lambertiana)	50	27	26
Sitka spruce (Picea sitchensis)	33	26	25
Redwood (Sequoia sempervirens)	38	24	23
Western red cedar (Thuja plicata)	24	22	21

Moisture in wood:- Study Article 159. Water exists in only two conditions in wood, - (1) as free water in the pores and (2) as absorbed water in the cell walls. (1) and (2) as given in the text are practically identical. The moisture content of green wood as given in Table I, facing page 196, is computed on the basis of

specimens dried to a constant weight at 100 degrees Centigrade.

The drying of timber:- Study Article 160. The principal reasons for seasoning wood are given in the first part of Article 160. Most wood is seasoned in the open air, Under these conditions the rate of drying varies with the temperature and humidity of the air, size and species of wood and method of piling. Sawed lumber is piled so as to permit the free circulation of air. In piling wood for air-seasoning care must be taken to have good foundations for the stacks, which must be kept free from debris and the yards should be well drained. Air seasoning usually takes considerable time as indicated in Figure 6 on page 151. Defects produced by improper drying have sometimes caused losses of 25% of the seasoned wood.

Kiln drying is resorted to when wood must be seasoned quickly. A recent development of a kiln-drying process which makes use of superheated steam has been announced by the U.S. Forest Products Laboratory. Green coniferous lumber (such as Douglas Fir and Southern Yellow Pine) one inch thick can be dried to 10 % moisture content in 24 hours by this method. It is not recommended for lumber over 2 inches thick.

In the rapid seasoning of wood care must be taken to prevent the evaporation of water from the surface at a faster rate than it is brought from the interior of the wood. The surface evaporation can be controlled in a well designed kiln by regulating the humidity, temperature and amount of air passing through the kiln. Evaporation in a kiln depends upon the relative humidity of the air. Air with a relative humidity of 100 % cannot dry wood because it already

contains all the water it can carry, but if the relative humidity is reduced to say 60 % it can take up a certain amount of moisture. A large amount of air is required in the successful operation of a kiln. Typical kiln conditions in drying 2 inch thick fir are as follows: The wood is given a preliminary steaming for several hours, the temperature is about 130 degrees Fahrenheit, the relative humidity of the air is 100 % and the moisture in the wood about 60 %. The object of this preliminary treatment is to soften the surface in case it has been casehardened and also to facilitate the transmission of water from the interior of the wood. The temperature then drops to 110 and the relative humidity of the air decreases to 80 %. The temperature is then gradually increased and the relative humidity of the air decreased. Due to these changes the moisture in the wood is decreased gradually to about 30 % at the end of the first week. At the end of twenty days, with the temperature gradually increasing to 150 degrees Fahrenheit and the relative humidity of the air decreasing to 30% the wood has been reduced to a moisture content of 10%. Any casehardening that has been produced is then removed by a final steaming of a few hours duration, during which the temperature is 160 and the relative humidity of the air is 100%. This treatment increases the moisture content of the wood to 15%, which is again reduced to 10% by a few hours drying under the conditions just preceding the final steaming.

The moisture in wood will tend to come to equilibrium with that of the air in which it is stored. Kiln-dry wood (about 8% moisture) will reabsorb water if stored under open-air sheds so that

its moisture content will be about 15%. The time required for such readjustment depends upon the size and shape of the pieces. Air-dry wood if stored in a wood-working shop will tend to come to a moisture content of about 6 %. This shows that wood is a hygroscopic substance. Since changes in the moisture content produce changes in the dimensions of cut lumber it is essential that the moisture content of the wood at the time it is used in cabinet work and other exact construction be the same as it would be under conditions of later use. High-grade furniture is varnished or given other surface treatment on all exposed surfaces (back and underneath) so as to reduce the tendency of the thoroughly-seasoned wood to absorb water, which would cause it to swell, or to give off moisture and produce shrinkage. Paraffin has been found to be the most effective substance used to treat air-dry wood so as to prevent shrinkage and swelling when the wood is subjected to atmospheres of variable humidities.

The table at the bottom of page 152 is not important.

Shrinkage and its effects:- Study Article 161. The removal of free water reduces the weight of wood but it does not affect the other properties. When all the free water is removed the fiber-saturation point is reached. Further decrease in water content causes wood to shrink. See Figure 12 on page 156. The fiber-saturation point usually ranges from 25 to 30% of the dry weight of the wood. The common defects produced by improper seasoning are checking, case-hardening, honeycombing, and warping. Each of these defects is explained in this article.

Amount of shrinkage:- Study Article 162. Wood in an air-dry condition has reached about one-half of its possible shrinkage. Lengthwise shrinkage is negligible because the thickness of the end walls of the wood elements is very small when compared to the length of these elements. Shrinkage in a direction tangential to the annual rings is about twice as great as in a radial direction. Considerable force is developed when confined wood swells due to the absorption of water. This is strikingly shown in an illustration in Engineering news, 70, 615, September 25, 1913. Slabs of oak veneered with maple were stacked in a basement to within 1 inch of the lower side of a 12 by 24 inch reinforced concrete beam which formed part of the first floor framing. The wood was saturated during a flood which caused it to swell. The force developed, raised the beam 3 inches at the point of contact making its replacement necessary. The shrinkage from green to over-dry condition for different species of wood is given in Table I, which faces page 196.

Principal native woods:- Study Articles 167, 168, 173, 174, 185, and 189. They give data on Western Yellow Pine, Sugar Pine, Douglas Fir, Western Hemlock, Redwood, and Western Cedar respectively. These are the principal species of wood grown on the Pacific Coast. Article 164 describes Southern Yellow Pine which is an important species of wood; in its properties and uses it resembles our Douglas Fir.

Read the other articles, not listed above, up to Article 197.

1. Name the principal woods grown in the Pacific Cost forests.

2. Distinguish between wood, timber, and lumber.

3. Sketch the cross-section of a tree and show the bark, heart-wood, cambium, pith, summer wood, sapwood, and spring wood.

4. What are the common defects in structural timber?

5. What is the approximate weight of air-dry wood? (Be sure to give unit of measure)

6. What are the reasons for seasoning wood?

7. How is wood seasoned?

8. What is the fiber-saturation point? What is its significance?

UNIVERSITY OF CALIFORNIA EXTENSION DIVISION

Correspondence Courses

Materials of Engineering Construction

Civil Engr-8. Professor C. T. Wiskocil

Assignment 5.

DETERIORATION AND PRESERVATION OF WOOD

Reading Assignment:- Johnson's Materials of Construction, Chapter V, pages 179 to 194 inclusive.

The Durability of Wood:- The durability of wood depends upon the conditions under which it is used. The life of Sycamore lumber, when placed under conditions which subject it to decay, is from three to five years. Weiss, in his book, Preservation of Structural Timbers, gives an illustration of an Egyptian coffin of Sycamore dating from the XII dynasty (2000 - 1788 B.C.) which is still in perfect condition. When wood is kept dry its resistance to decay is indefinite.

Black locust and osage orange are probably the most durable woods. Their life is estimated as being over 15 years, even under adverse conditions. They are used principally for planing mill products, vehicle and vehicle parts, and ship and boat construction. The life of redwood and cypress is from 12 to 15 years under similar conditions. These woods are used principally for planing mill products and general mill work. The amount of cypress used is about six times that of redwood. Redwood is known to have lasted for much longer periods. Stakes 2 by 3 inches in section driven by the U.S. Coast and Geodetic Survey along the California coast in 1874 were found in a fair state of preservation in 1921, 47 years after having been driven into the ground. Large redwood sills under a

bridge pier near Healdsburg, California, were recently (December 1921) found to be in a perfect state of preservation, 35 years after being placed in a position which was above low water level. Douglas fir and southern yellow pine, the principal structural woods, have an estimated life of 9 to 11 years when placed under conditions subjecting them to decay.

In general, sapwood is less resistant to decay than heartwood, and, when used without preservative treatment in situations favorable to decay, sapwood is likely to have much shorter life than heartwood. But when properly treated sapwood and heartwood are practically equal in resistance to decay.

Some woods are more durable than others. The reason for this difference is not known. Density does not seem to be a criterion of durability. Durability, however, can be judged by the presence of sapwood, the moisture content, the presence of sap stain, structural defects, and the amount of resin. Pronounced variations in color, especially when wood is spotted or streaked, indicate incipient decay. Resin keeps out moisture and air and thus acts as a preservative. Fence posts having a high pitch content last longer than those having less pitch. Such defects as checks and knot holes offer places for the lodgement of the spores of fungi and form starting places for decay.

The color of cypress was thought to be a criterion of its resistance to decay. But investigations by the U.S. Forest Products Laboratory have proved that the color of the wood makes little

difference. If durability is desired it is important to select heartwood of cypress regardless of its color.

The moisture content of wood to be used in building construction, particularly in poorly ventilated places, is of importance because poor ventilation is favorable to the attack of the so-called "dry rot". (See discussion on page 181). Mill construction with poorly seasoned wood has been known to have become infected within a year or two after completion, whereas well seasoned wood has resisted decay under similar conditions for more than ten years. The term "dry rot" is frequently applied to any decay in comparatively dry wood. Dry rot, however, is the result of the attack of the house fungus, merulius lachrymans, which is frequently found growing in dry wood without any apparent supply of moisture. The U.S. Forest Products Laboratory has proved that this fungus will not grow in thoroughly dry wood but it will germinate in moist wood and make its way for long distances into dry wood, drawing the necessary water from the moist wood through a system of minute porous strands. Wood in the advanced stage of dry rot is shrunken, yellow to brown in color, and so brittle that it can easily be crushed into powder. The dry rot fungus is active throughout this country attacking coniferous woods more commonly than the dicotyledons.

The following are the principal causes for the rapid deterioration of wood in buildings:

1. The use of green lumber.
2. Allowing lumber to get wet during construction.
3. Allowing lumber to absorb moisture after the building is completed, because of leaks or lack of ventilation.
4. The use of lumber containing too much sapwood.
5. The use of lumber which has already started to decay

The avoidance of these conditions will, as a rule, prevent decay. In certain cases, however, decay can only be prevented by preservative treatment.

The chief causes for deterioration are decay, marine borers, insects, mechanical abrasion, and fire. Birds and alkali soils cause deterioration but it is estimated that decay is the most important.

Composition of Wood:- Read Article 202. In the previous assignment the composition of wood was given as lignocellulose, which is a starch-like substance, permeated by lignin, resin, coloring-matter, water, and a small proportion of inorganic matter.

Causes of Decay:- Study Article 203. The attack of bacteria and fungi cause the decay of wood. Only a small percentage of these parasites, which are low forms of plant life, have the ability to decay wood. Most wood-rotting fungi thrive at temperatures around 80 degrees Fahrenheit; small rises above this optimum temperature are often fatal. It is good practice to heat newly completed wood buildings in order to kill surface growths of fungi. Practically all fungi survive the coldest winters. Spores of fungi are known to have remained alive for 8 years when in a dry condition.

Insects:- Study Article 204. Insects damage wood in any form by cutting out burrows or galleries. Borers like termites and powder-post borers, enter the stick of wood through a small hole and then excavate winding burrows, whose extent cannot be estimated by surfact indications. White ants or termites, black ants, carpenter bees, and powder-post borers are the principal wood boring insects. It has been reported (1922) that in some localities near Los Angeles, California, as many as 50% of the cedar poles set by the Southern

California Edison Company prior to 1910 have been attacked by termites. The infected area extends from San Diego to Santa Barbara and east to Redlands. The insects enter the poles at the ground line and frequently attack the pins on the cross-arms without coming to the surface of the pole. Creosote oil has been found to be an effective preservative.

Marine Borers:- Study Article 205. Destruction by marine borers during 1919 and 1920 in San Francisco Bay and the adjoining San Pablo Bay and Suisun Bay has been estimated by a committee of the American Wood Preservers' Association who reported in "San Francisco Bay Marine Piling Survey", to be in excess of 15 million dollars. There are three species of molluscan borers: Teredo navalis, Teredo diegensis, ... and Xylotraya setacea, besides three species of crustacean borers: Limnoria, Sphaeroma and Chelura, active in this region. Where the attack of these borers is severe, untreated piles are destroyed in 6 to 8 months. In other places they may last 2 to 4 years. Properly creosoted piles of Douglas Fir have a life of about 25 years. Destruction of creosoted piles has been the result of untreated wood being exposed to attack by damage to the surface in handling or placing the piles. Various kinds of protection to wood piles have not been very effective. Preservative treatment with creosote has been most satisfactory. The attacks of marine borers is not new. They were known to the ancient Romans. The following note was taken from Voyages and Travels, Vol. II, C.R. Beazley, in regard to the ships sent out to discover

the Northwest Passage during the reign of Henry VI:

> "They cover a piece of the keels of the shippe with their sheets of leade, for they had heard that in certaine partes of the ocean a kinds of wormes is bredde, which many times pearceth and eateth through the strongest oake that is."

Other Deteriorating Influences:- Read Article 206. Mechanical abrasion and fire are important destroyers of wood, whereas alkali soils, and birds are only minor causes of deterioration.

The Need of Preservation:- Read Article 207. The idea of wood preservation is not new. Pliny writes that in his time, wood was protected from attacks by worms by treating it with garlic boiled in vinegar. The early Greeks and Romans used the oils from Cedars and Junipers for their antiseptic value. These oils were rubbed over the surface of the wood to be preserved. The Britons made various attempts to protect their wooden warships from decay. Wood preservation is now practiced all over the world. The necessity of preservation is given in the text (Article 207). There are two methods of protecting wood from destruction by living organisms. The first is to control the conditions necessary for life and thus inhibit their growth. This means the control of the temperature and the moisture content, which is not practical in the commercial use of wood. The second method is to inject a material which will kill or poison the organisms themselves or the enzymes through which they accomplish their destruction. This latter method is now the

standard practice.

The Relation of Structure to the Penetration of Preservatives:- Study Article 208. This article shows the effect of the various structures upon the diffusion of preservatives and indicates why all woods cannot be given the same treatment if uniform results are to be expected. Douglas Fir, as noted, cannot be easily impregnated. It is now being mechanically perforated so that a uniform, predetermined, penetration of preservative can be secured.

The Treatment of Timber before Preservation:- Study Article 209. Wood is thoroughly seasoned before being given preservative treatment. The preliminary treatment is described in this article.

Superficial Treatments:- Read Articles 210 to 213 inclusive. Superficial processes simply give the wood a thin surface coating of preservative. Timber so treated is apt to have the protecting coating broken either by abrasion or checking which exposes untreated wood and subjects the entire piece to decay.

Superficial processes are inexpensive and are used only when small quantities of wood are treated. Dipping is more effective than brush treatment. Recent tests by the U.S. Forest Products Laboratory have proved that charred posts were less durable than untreated ones. The charred surface is usually not a solid covering. It is checked through in many places. If seasoned posts are charred the charring does not reach to the bottom of the season checks which are always present. If green posts are charred season checks open up through the charred exterior. In either case the

uncharred interior is exposed to infection and will decay as rapidly as untreated wood. Charring deep enough to resist decay would undoubtedly weaken a post of ordinary size.

Non-Pressure Processes of Impregnation:- Study Articles 214 to 216 inclusive. Non-pressure methods are carried on in open tanks. They insure a better penetration than is obtained by the superficial processes. Open-tank and Kyanizing are the two non-pressure impregnation processes now in use. They differ from pressure processes in that the latter use pressures above atmospheric to force the preservative into the wood. Farmers and mine and telephone companies are the principal users of open-tank methods of preserving wood. Mercuric chloride was first used as a wood preservative in 1705. The process of preservation in which this salt is used was patented in England by John H. Kyan in 1832. It was introduced into the United States about 1840 and is said to be the oldest method of treating wood now practiced in this country. The details of the process are given in Article 216.

Pressure Processes of Impregnation:- Study Articles 217 to 223 inclusive. Pressure processes use pressures above atmospheric to force preservative into the wood. The Bethell process (Article 219) is named after John Bethell who took out patents in England in 1838. It is commonly called the full-cell process. Green or seasoned wood can be treated by this method. It is considered the standard process of treating wood with creosote. The process has been modified because of its excessive use in preservation.

The boiling process (Article 220) was patented in the United States by W.G. Curtis and J.D. Isaacs in 1895. With the exception of the preliminary treatment which the wood is given, it resembles the Bethell process.

The Lowry process (Article 222) is sometimes called the empty-cell process. It was patented in the United States by C.B. Lowry in 1906.

The Rueping process (Article 220) is also called an empty-cell process. It was patented in 1902.

The Card process (Article 223) was patented in 1906 by J.B. Card.

The Burnett process (Article 219) was patented in England in 1838 by William Burnett. It is the standard zinc chloride process.

Study these pressure methods and be able to outline the process and give the kind of preservative used in each.

Preservatives:- Study Article 224, which describes the preservatives commonly used for treating wood. The principal requirement for a good preservative is that it be able to kill the organisms which attack wood or destroy the agents (enzymes) through which these organisms work. In addition the preservative must be soluble in the body fluids of the organisms. Since organisms which attack wood have water as their chief body fluid, it is necessary that a material to be toxic must be soluble in water to a certain extent. In this respect oil solutions and inorganic salts must be similar. Wood impregnated with zinc chloride has all the toxic zinc in solution

and the concentration of this zinc becomes weaker and weaker by any leaching to which the wood may be subjected. Creosote oil, which may include hydrocarbons (such as benzene, toluene and naphthalene) or tar acids (such as the cresols and naphthols) or tar bases (such as quinoline and isoquinoline) or a combination of all three, is (according to Bateman) divided into two groups. The first one contains those oils that are sufficiently soluble in water to render their water solutions capable of killing the wood-destroying organisms and are called toxic oils. The second group, which are called non-toxic oils, are not sufficiently soluble to produce a toxic water solution. Toxic oils are completely soluble in non-toxic oils and are partially soluble in water. The toxic oils, therefore, divide themselves between the water and the non-toxic oils in such a manner that their concentration in water and the non-toxic oils is in propertion to their solubility in the respective media. The non-toxic oils act as a reservoir for the toxic oils. Assume a toxic oil as being 50 times as soluble in a non-toxic oil as it is in water. Take a 10% solution of the toxic oil in the non-toxic oil. When such a solution comes in contact with an equal volume of water the concentration of the water will be 0.2%. If the toxic limit of the water solution is 0.05% then the water solution is four times as toxic as is necessary to kill. Suppose that this water is withdrawn and an equal amount added, which in turn takes up its proportion of toxic oil. This change of water could take place seventy times before the toxicity of the water would be below killing point. This is Bateman's theory.

In actual practice the rapidity of this change depends upon the conditions under which the wood is used. If alternately wet and dry, such as piling between high and low tides, a high rate of depletion of preservative could be expected. A much slower rate of solution would take place in dry places, such as those of telephone poles.

The difference between oil and inorganic salt preservatives according to this theory is in the method of retaining the reserve supply of toxic materials. Zinc chloride has no reserve supply, all of the material is soluble in the usual amount of moisture present in air-dry wood.

Bateman has proved his theory by experiments with tar acids.

Study this theory carefully and compare it with statements in Article 224 in the text.

Article 225 is relatively unimportant - omit it.

1. What are the principal causes for the deterioration of woods?

2. What causes wood to decay?

3. What is dry-rot? How can it be prevented?

4. Differentiate between the attack on wood piles of the limnoria and the teredo.

5. What methods are used to preserve wood?

6. Outline the full-cell process. What are its disadvantages?

7. Name the preservatives commonly used for impregnating wood as protection against attack of living organisms.

8. Explain why creosote is more effective than zinc chloride in preserving wood when it is subjected to alternate wetting and drying.

UNIVERSITY OF CALIFORNIA EXTENSION DIVISION

Correspondence Courses

Materials of Engineering Construction

Civil Engr-8. Professor C.T. Wiskocil

Assignment 6.

The Mechanical Properties of Wood

Introduction:- Read Article 226. The effective use of wood requires a thorough knowledge of the factors which affect its mechanical properties. Some of these factors have already been studied but in this assignment their relative importance will be emphasized.

When comparing the general quality and the strength of wood, the term "strength" must be carefully defined. In the strict sense, strength means the ability to resist a definite stress or load, as compressive strength. Generally the term strength may have a number of meanings, depending upon how the wood is used. In the case of beams, transverse or bending strength is implied, in columns compressive strength is meant, whereas for implement handles both hardness and toughness are included in the term strength.

Table I, in the text, gives comparative values of the mechanical properties of woods. A more comprehensive compilation of test results is given in "MECHANICAL PROPERTIES OF WOODS GROWN IN THE UNITED STATES" by Newlin and Wilson, Forest Service Bulletin 556, United States Department of Agriculture, from which the following table is abstracted:

The Industrial Democracy of Rome

Strength of wood (Taken from Forest Service Bulletin 556) Air Dry and Green

Common and Botanical Name	Moisture Content (Per cent)	No. of Rings per in.	Bending Strength lb/ sq in.		Compression strength-lb/sq"		Strength in Shear lb/sq " // to grain	Stiffness in Bending. Mod. of Elast. lb/ sq "	Shock resisting ability. Ht. of drop of 50 lb,, to hammer to produce failure
			Fiber stress at elastic limit	Mod. of Rupture.	// to grain (max)	⊥ to grain (elas. lim.)			
Douglas Fir (Pseudotsuga taxifolio)	9.4	22	6900	10300	7090	950	1080	1,460,000	28
Douglas Fir (Pseudotsuga taxifolio)	38.	22	3600	6400	3000	450	880	1,180,000	20
Western Yellow Pine (Pinus ponderosa)	10.8	20	6900	9800	6000	760	1160	1,340,000	16
Western Yellow Pine (Pinus ponderosa)	95.	20	3100	5200	2460	340	680	1,010 000	19
Sugar Pine (Pinus lambertiana)	11.4	12	6400	8600	5190	640	1080	1,210,000	17
Sugar Pine (Pinus lambertiana)	123.	12	3300	5300	2600	350	710	970,000	17
White Oak (Quercus alba)	11.8	17	8300	15200	7610	1340	2090	1,780,000	38
White Oak (Quercus alba)	68.	17	4700	8300	3560	830	1250	1,250,000	42

Table I is an excellent reference. If recent data are needed Forest Service Bulletin 556 will be found to be more complete. It is a good idea to take some common species of wood such as Douglas Fir and remember the data, given in the abstracted table in these notes, for the wood in the green condition. Most of the tests from which such values are obtained were made at the Forest Products Laboratory at Madison, Wisconsin (see page 195 in text).

The test pieces were all straight-grained and free from defects, such as knots, shakes and checks, and in the same condition of seasoning. The values given were based on about 130,000 tests on 126 species of wood. Data are given for green and air dry conditions because the properties of all species are not changed in the same proportion by drying and all the properties are not equally affected. Air-dry woods should have the same moisture content in order to be strictly comparable, but in the case of wood in the green condition, even though quite different for the different species, the moisture content is above the fiber saturation point and above this point changes in moisture do not affect the strength. Tests on individual pieces may be expected to vary from $\pm$ 7 to $\pm$ 14% from the values given in these tables.

Compressive Strength:- Study Article 227. The compressive strength parallel to the grain is important in estimating the strength of columns and struts. It is determined by tests on 2 by 2 by 8 inch specimens. A compressometer with a 6 inch gage length is used so that the elastic limit and the modulus of elasticity can be determined. A typical curve is shown in Figure 6 on page 210. The maximum

strength is more easily determined than elastic limit strength and is also less variable. Working stresses must be well below the elastic limit. For columns in dry interior construction having a length less than 10 times the least dimension, a working stress of about 1/3 of the compressive strength of green wood is used.

Wood is also tested in compression perpendicular to the grain. The specimen is 2 by 2 by 6 inches with the load applied through a steel plate 2 inches wide. The area under load is, therefore, 4 sq inches. A deflectometer of the type shown in Figure 48 on page 89 is used to get a stress-deformation curve similar to the one shown in Figure 6 on page 210. Only the stress at the elastic limit is determined because this is the maximum stress that can be applied without injury. Greater loads crush the specimen without a definite point of failure. Furthermore, the deformation measurements are easily obtained so that the elastic-limit determination is a simple one. Strength perpendicular to the grain is developed in bearing areas of beams, railroad ties, and in any construction where the load is similarly applied. A working stress of approximately 2/3 the elastic limit of green wood may be safely used in dry interior construction. Omit Tables 2 and 3; They are useful only when specific information is needed.

Tensile strength of wood:- Read Article 228. The tensile strength of wood parallel to the grain is rarely determined. The Forest Service tests the tensile strength perpendicular to the grain. The form of specimen and the manner of loading are shown in Figure 1 on page 201. The data from this test are of value in establishing

the resistance of wood to the splitting action of bolts and other fastenings.

The shearing strength of wood:- Read Article 229. Shearing stress parallel to the grain is developed in most structural uses of wood. It is of importance in beams (see Figure 2 on page 202), where it is called horizontal or longitudinal shear. It is also of importance in the design of wooden joints (see Figure 3 on page 203). Shearing stress across the grain is rarely listed. The specimen and the method of making the shearing test parallel to the grain are shown in Figure 14 on page 63. Longitudinal shear is greatest at the neutral surface of the beam and is affected by checks and shakes which reduce the effective area resisting shearing stresses. These defects must be expected in structural timber; therefore safe working stresses for longitudinal shear in beams are about 1/8 of the values obtained from tests on clear, straight grained pieces. For joints and small details where checks and shakes can be avoided the working stress may be increased to 1/4 the strength of green wood. Omit Tables 4 and 5.

Transverse strength of wood:- Study Article 230. This property of wood is determined by the static bending test. The specimen is 2 by 2 by 30 inches, tested on a 28-inch span. The load is applied at the center. A deflectometer is used so that a load-deflection curve similar to that in Figure 6 on page 210 can be drawn. Large timbers are loaded at the third-points as shown in Figure 2 on page 202. The static bending test is easily made and yields important data. Working stresses in bending must be below the elastic limit

for if wood is stressed to its elastic limit in static bending it will ultimately fail. Determinations of elastic limit are not so reliable as those of the maximum fiber stress, which is known as the modulus of rupture. Working stresses should, therefore, be based on the latter. Remember that the modulus of rupture is not the actual fiber stress, because it is based upon a theory which is valid only when the elastic limit is not exceeded.

A green timber relatively free from defects will have a modulus of rupture of about 3/4 as large as small clear pieces cut from it.

Safe working stresses for structural timber in interior construction should be about 1/5 the modulus of rupture for green wood. For exposed construction the working stresses should be lower. Strength in longitudinal shear must also be considered when designing wooden beams. Omit Table 6.

The time element in loading wood:- Read Article 231. The strength of wood is affected by the rate at which the test load is applied. The speed of testing should, therefore, be considered (See the Forest Service program as given in this article). The most important fact in this article is that the resistance of wood under permanent loads is less than when it is under temporary loads. It takes about 50% of the ultimate load as applied in a testing machine to cause failure if permanently applied. This is another reason why working stresses are so low when compared with ultimate strength as determined by tests made in a testing machine.

Stiffness and other mechanical properties:- Study Articles 232, 233, 234 and 235. Stiffness, which is measured by the modulus of elasticity, has an average value of about 1,200,000 lb. per sq. in. In the case of a beam the modulus of elasticity is a measure of its resistance to deflection. The importance of this property is indicated in Article 232. Green wood is not so stiff as air seasoned wood. Stiffness is usually determined in the static bending test.

Toughness is sometimes defined as the ability of wood to withstand impact loads. Impact loads are sustained by spokes of an automobile wheel, ax or implement handles and athletic goods such as baseball bats. A measure of toughness is obtained by the impact bending test and the energy of rupture in the static bending test. Impact bending is made on a 2 by 2 by 30 inch specimen tested on a 28 inch span. The machine used is shown in Figure 19 on page 66. A 50 lb. hammer is usually used. The height of drop to produce failure indicates the toughness of the wood as stated in Article 233. Wood in the green condition is tougher than after it is seasoned. A suddenly applied load has twice the effective force as when gradually applied. The fiber stress at the elastic limit in impact is approximately double the fiber stress at the elastic limit in static bending. Stated in another way: a small beam, if the load is suddenly applied, will deflect twice as much as under the same load gradually applied - provided the loads are under the elastic limit.

The height of drop is an arbitrary value but it gives an excellent comparison of the toughness of the different woods tested.

While cleavability is an important property in some uses of wood, it is not usually tested. A special test for it is described in Article 234.

The hardness of wood is frequently determined. The method is to measure the load required to embed a 0.444 inch ball to 1/2 its diameter in the wood. The test is applied to end, tangential, and radial surfaces. Radial and tangential hardness are quite similar and are called side hardness as distinguished from end hardness, which is usually much greater. Hardness is an important quality in wood used for paving blocks, floors, railroad ties, and furniture. Read Article 235 in the text.

Conditions affecting Mechanical Properties of timber:- Read carefully Articles 236 to 245 inclusive. Differences in the strength of wood are usually due to differences in defects, moisture content, or density. Defects, while discussed at this time, would be more properly taken up under the subject of grading. The most important conditions, then, which affect the mechanical properties of wood are moisture and density.

Density or specific gravity was defined under the subject of physical properties of wood. Apparent specific gravity (the ratio of the weight of a given volume of wood to the weight of an equal volume of water) is an indefinite quantity unless the circumstances under which it is determined are specified, because the weight in a given volume changes with the shrinkage and swelling caused by changes in the moisture content. Specific gravity is based on the

volume of wood when green, and when air-dry or oven-dry. Specific gravity based on green volume is not affected by the shrinkage of wood and is therefore more reliable than air or oven dry specific gravity.

Note: Correction is made for the amount of moisture in the wood.

Specific gravity, aside from actual strength test data, is the most reliable criterion on the strength of clear wood. The Forest Products Laboratory examined seven species of woods, both conifers and dicotyledons and found only a 4 1/2 % variation in the specific gravity of the wood substance. The specific gravity of a piece of wood is, therefore, a measure of the amount of wood substance it contains. The greater the density the more wood it contains and therefore the greater its strength. This relation is shown in Figure 8 on page 213.

Since the weight per cubic foot depends upon the moisture in a green wood, it is quite variable. The conditions under which it is obtained should, therefore, be specified.

The effect of rate of growth, measured by the number of rings per inch, is shown in Figure 10 on page 215. Rate of growth is extremely variable. The curves show no definite relation between rate of growth and strength. Wood which has grown slowly is usually below average strength. In coniferous wood of very rapid growth the strength is also likely to be below average. In the dicotyledons, however, the wood of rapid growth is usually above average strength.

The amount of summerwood in any species is indicative of

the density. The amount of summerwood is measured along a representative radial line and expressed in percentage of the entire area. When the difference in color between spring and summer (early and late) wood is not clear and distinct, accurate measurements cannot be made and the results are of no practical value. The relation of the percentage of summerwood to certain mechanical properties are given in Figure 12 on page 216.

Differences in strength of wood as caused by differences in location, of growth, and of differences in position in the tree have usually been overestimated.

The influence of defects such as knots, checks, and shakes is described in Article 240. Study this article carefully.

Heartwood and Sapwood:- The difference between the strength of heartwood and sapwood is not discussed in the text. The following statement is taken from a recent report by the Forest Products Laboratory: "In over 300,000 tests which have been made at the Forest Products Laboratory, Madison, Wisconsin, on the various species of wood grown in the United States, no effect upon the mechanical properties of wood due to its change from sapwood into heartwood has ever been noticed. Any difference in the strength of heartwood and sapwood can usually be explained by the growth and density of the wood".

Comparative value of wood cut from live and dead trees:- This subject is not discussed in the text but some specifications preclude the use of lumber cut from dead trees. This subject has been studied at the Forest Products Laboratory and they report that there

is no known method by which lumber cut from dead trees can be distinguished from that cut from live trees. Furthermore all available information indicates that wood cut from insect or fire killed trees is just as good for any structural purpose as that cut from live trees of similar quality, providing the wood has not been subsequently injured by decay or further insect attack. Heartwood in a living tree is entirely dead and in the sapwood only a few cells are alive. Most of the wood cut from trees is dead, regardless of whether the tree itself is living or not. Specifications, instead of providing that wood must be cut from live trees, should state that material showing evidence of decay or insect attack exceeding a definite limit will not be accepted.

Articles 242 to 245 are relatively unimportant - just read them over. In the case of preservatives, Article 243, it would be more exact to say that the effect of preservative treatment on the strength of wood is independant of the type of preservative because it is the method or process and not the kind of preservative used that affects the strength of wood. Creosote, which is the most common preservative, does not appear to effect the strength of wood. A preservative process that weakens one species of wood may not affect the strength of another species. The results are also affected by the form and size of timber treated as well as its condition.

Article 241 - <u>The Effect of Moisture on the Mechanical Properties</u>. The relation between moisture content and strength is

clearly shown in Figure 15 on page 220. This is for small, clear pieces. For large timbers, the increase in strength produced by a decrease in moisture is often entirely offset by checks and similar defects which develop during the seasoning process. Under most conditions it is advisable not to expect additional strength due to seasoning. Seasoning of beams increases the liability to failure by horizontal shear. The curves shown are typical. The importance of the fiber-saturation point is evident from this illustration. It occurs at about 25% moisture. Table I opposite page 196 was obtained from small green sticks which were clear, straight grained, and free from defects. In general, air dry wood is about 50% stronger and kiln dry wood is about 100% stronger than wood in the green condition. Resoaked wood is not so strong as green wood.

The modulus of rupture in static bending and the compressive strength parallel to the grain are changed about 4% by a change of 1% in moisture content (when it is about 12%). For example, compare the modulus of rupture of Douglas Fir and Western Yellow Pine as given in the table in these notes. Douglas Fir at 9.4% moisture has a modulus of rupture of 10,300 lb. per sq. in. The Western Yellow Pine has a moisture content of 10.8% with a modulus of rupture of 9,800 lb. per sq. in. To change the latter to 9.4% moisture will increase the strength

$$(10.8 - 9.4) \times 4 = 5.6\%$$
$$.056 \times 9{,}800 = 550 \text{ lb. per sq. in.}$$
$$550 + 9{,}800 = 10{,}350 \text{ lb. per sq. in.}$$

The modulus of rupture of Western Yellow Pine at 9.4% moisture is, therefore, about 10,350 lb. persq. in. For large differences in moisture content this 4% difference in strenth will not be accurate.

Strength of Nails in Wood:- Read Articles 246 to 248 inclusive. The holding force of nails, expressed in terms of adhesive strength, in lb. per sq. in. of imbedded surface varies with the density of the wood and the form of the nail.

The most recent tests, reported in Bulletin No. 1, "Tests on the Holding Power of Railroad Spikes", by Beyer and Krefeld, Department of Civil Engineering, Columbia University, show that the driving of spikes into holes, bored into the tie to receive them, reduces the crushing and bunching of the wood fibers. The pre-bored hole increases the resistance to withdrawal of the spike. In soft woods the elastic limit of the fastening is reached at very small withdrawals - 0.004 to 0.006 inches - and in oak the elastic limit is somewhat higher. A rail fastening, to approach permanance, must at no time be stressed beyond its elastic limit holding power.

The shearing strength of nails, in nailed joints, varies with the density of the wood and the size and depth of penetration of the nail.

Working Stresses:- Study Article 249. Safe working stress for a material is the unit stress which, under conditions of use, will not cause structural damage. Working stresses must be considerably below the ultimate strength of the material for several reasons. (a) Where stressed to the point of failure materials undergo

marked distortion and have less stiffness. These changes would cause unsatisfactory service in the case of a machine or structure. (b) The exact loading to which a structure will be subjected cannot be determined. Actual conditions may vary considerably from design assumptions. (c) Structures are liable to overload and some margin of safety must be provided for such contingencies. (d) The exact strength of the materials used is never available, furthermore the strength may be affected by deterioration or accidental damage.

Where human life is endangered by failure of a structure, working stresses should be low. Under other conditions where the results of temporary collapse are not important, the use of higher stresses are justified.

Working stresses are frequently determined by dividing the ultimate strength of the material, as determined by actual test, by a factor of safety. This factor varies from 2.5 to as much as 20 for different materials and different conditions of use. If a structure is designed with a factor of safety of 4, it does not mean that it will fail at four times the working or design load. Working stresses should be based on and be well below the elastic limit of the material.

All large timbers, since they have season checks, knots and other defects should not be considered to be stronger than green timber. Working stresses should be based on tests of green wood.

In the design of wooden structures it should be remembered that the actual dimensions of commercial lumber are usually less

than the nominal dimensions. Sawed lumber is not considered as "short" in dimensions unless an actual dimension is 1/4 inch or more less than nominal. For dressed lumber (as lumber which has been planed is known) an allowance of 1/4 inch for each dressed face is made. A 12 by 12 inch stick, if dressed on four sides, would, therefore, actually measure about 11 1/2 by 11 1/2 inches.

Working stresses for structural timbers which pass the grading rules proposed by the Forest Products Laboratory are affected by the moisture content. The following table was taken from recent Forest Service publications:

Working Stresses Permissible for Structural Timbers, lb. per sq. in.

Species	Bending				Compression					
	Stress in extreme fiber			Horizontal Shear	// to grain			⊥ to grain		
	Wet location	Outside location	Inside location	All locations	Wet location	Outside location	Inside location	Wet location	Outside location	Inside location
Douglas Fir (No.1 Structural)	1100	1400	1600	100	900	1100	1200	225	250	350
Douglas Fir (No.2 Structural)	900	1100	1300	90	800	900	1000	200	225	300
Western Hemlock	900	1100	1300	75	800	900	900	200	225	300
Redwood	800	1000	1200	70	750	900	1000	125	160	250

Wet or damp location - docks, piling, and sills
Outside location - not in contact with soil, bridges, and open sheds
Inside location - under shelter in a dry location, factories and warehouses.

Grading rules:- Read Article 250. Structural timbers are graded or classified, by inspection, into groups or grades so that each stick in a given group will have the same value for a certain purpose. Grading rules are generally prepared by timber producers such as saw mill associations and lumber manufacturers' associations while timber specifications, which are written for the purpose of having timber that fulfills the requirements suitable for a definite purpose, are prepared by the timber user.

Many grading rules are based on the number and the character of defects; they have been satisfactory in classifying saw mill products for wood working industries but they have not been effective in classifying timber in accordance with strength. The Forest Service, the American Society for Testing Materials, and the Southern Pine Association have adopted rules which provide for the quality of the wood as well as limit the position, size, and condition of defects.

Since the quality of wood is indicated by the character of the annual rings as seen on the cross section, and the location and size of defects, it is possible to use these factors in grading wood as to strength. Durability is judged largely from the proportion of sapwood which is less resistant to decay than heartwood. Durability is also affected by the degree of seasoning as indicated by the moisture content.

Study Figure 21 on page 232 and the text paragraph describing it.

Laminated Wood:- Wood, as has been thoroughly explained, is a non-homogeneous material. It has widely different properties in the various directions relative to the grain. Were wood homogeneous, with the same strength properties in all directions that it has parallel to the grain, it would be unexcelled for all structural uses where strength with small weight is desired. Laminated wood approaches this desired condition in that it produces equality of tensile strength in two directions - parallel and perpendicular to the board. Plywood is the name usually given to this type of construction.

Plywood is made by gluing together plies of wood, usually an odd number, so laid that the grain of alternate layers is approximately at right angles. Three-ply and five-ply construction is most common. The middle layer or core with equal layers on both sides gives a construction that is symmetrical causing an equalization of shrinkage stresses so that the wood should not warp. Warping does occur, however. The causes are first, the use of plain-sawed and quarter-sawed lumber in the same construction and second, the combination of materials of different moisture content. Both of these factors can be easily avoided. Moisture-resistant coatings are resorted to in order to maintain uniform moisture conditions in the wood. Plywood is used in the manufacture of automobiles, in street and railway cars, and in airplanes, where light construction is required.

Veneer is another type of laminated wood construction. Thin

sheets of hard wood known as veneer are glued to cheap lumber to give it a hard wood surface. Veneer is cut by three different methods. The oldest method is sawing, but the saw kerf which cannot be made much less than 1/20 of an inch wastes considerable wood. The second method is known as slicing. Veneer made by this method is essentially a thick shaving cut by a large plane. The third method is called the rotary-cut. A thin continuous sheet of veneer is cut off the surface of a log which is rotated in a huge lathe.

Sawed and sliced veneer are relatively expensive and are used primarily for ornamental and finish purposes. Most of the veneer produced at the present time is rotary cut. Veneer is used in the manufacture of plywood.

Average sawed veneer sheets are from 12 to 16 feet long, usually not less than 1/28 of an inch thick and their width is limited by the diameter of the log.

Sliced veneer is about 10 feet long and seldom less than 1/16 of an inch thick (but some species are cut 1/100 inch or less in thickness) and the diameter of the log in width.

Rotary-cut veneer is about six feet long, on an average, with a maximum length of 16 feet, some species may be cut from 1/100 inch to almost 1/2 inch in thickness and to any width in which the material can be handled.

Mill-Building Construction:- One of the uses of heavy timber is in the construction of large buildings. The marked success of early heavy timber structures of the mill-construction type, which

originated in the New England States, led to the popular use of this form of construction. The term mill-construction as commonly used is the name given to thattype of building construction in which the interior framing and floors are of timber, arranged in heavy solid masses with smooth flat surfaces, so as to expose the least number of corners, and to avoid concealed spaces which may not be reached readily in case of fire. As usually designed the walls are of brick or concrete, the floors are of heavy plank laid flat upon large girders which are spaced from 8 to 11 feet on centers. These girders are supported by wood posts or columns spaced from 16 to 25 feet apart.

1. Would a higher unit stress be allowable in a piece of spruce for a strut in an airplane frame or a strut in a large timber bridge? Why?

2. What are the most important tests of wood?

3. What is the importance of stiffness in wood? How is it measured?

4. What is the effect of permanent dead load on the resistance of wood?

5. Explain why the use of plain-sawed and quarter-sawed wood in the construction of a piece of plywood will cause warping under changes in moisture content.

6. Differentiate between grading rules and timber specifications.

7. What precautions are taken in the selection of test specimens?

8. Discuss the effect of moisture on the mechanical properties of wood.

9. Give the approximate ultimate strengths of Douglas Fir, in the air-dry condition, as determined by the usual tests made by the Forest Products Laboratory.

10. State the allowable working stresses for Douglas Fir when used in dry locations.

UNIVERSITY OF CALIFORNIA EXTENSION DIVISION

Correspondence Courses

Materials of Engineering Construction

Civil Engr.-8 Assignment 7 Prof. C. T. Wiskocil

BUILDING STONE

Uses and Production: Read Article 251. As stated in this article stone has been used asa building material since the earliest known times. It was used principally in the construction of walls, foundations, arches, and dams. Many old stone monuments are still in a fair state of preservation. Stone and wood are the only important structural materials used in their natural state. The use of stone for structural purposes is decreasing because of the development of reinforced concrete for these purposes. Half a century ago building stone composed nearly the entire output of the quarries. Some of it was made into lime but the use of concrete for foundations, bridges, culverts, curbing, and other structures has reduced the demand for building stone and lime. Important buildings in which appearance is a large factor, are still usually built of stone. About 70 million tons of stone are quarried annually in the United States. The approximate value of this output is 90 million dollars. These figures were taken from the United States Geological Survey reports from which the following table, showing the percentage of the entire output used for different purposes, was compiled:

Structural purposes	
Building stone	11.0%
Paving blocks	3.0
Curbing	1.0
Flagging	0.5
Rubble	1.0
Riprap	2.0
Crushed stone	38.0
Monumental stone	15.5
Furnace flux	20.0
Other uses	8.0

The last item includes stone used for such purposes as furnace linings, for which refractory stone - dolomite, quartzite, and mica schist - is required, and pulverized stone, used by sugar factories, paper mills, glass works, alkali and other industrial works.

Crushed stone is used for railroad ballast, roads, and concrete aggregate.

In Article 251, the part of the first paragraph which deals with the conditions which govern the selection of building stone, is important. It will be noted that strength is not included in these conditions. The compressive strength of stone is nearly sufficient to support safely, the weight of the superimposed masonry and other loads that come upon it. If a stone had a compressive strength of 6,000 lbs. per sq. in. and it weighed 170 lbs. per cubic foot, it would have to be built into a tower about 5,000 ft. high $\left(\frac{6000 \times 144}{170}\right)$ before the lowest block would be brought to the point of failure. The Washington Monument in Washington, D.C. is only 550 ft high and the Woolworth Building in New York City, with its 51 stories, is only 792 ft. high. These, to be sure, are not ordinary structures; but it should be remembered that there are

few stones that have an ultimate compressive strength less than 6,000 lbs. per sq. in. Granites average 20,000 lbs. per sq. in., while recently a Nephelite Basalt quarried near Austin, Texas was found to have an ultimate compressive strength of 53,900 lbs. per sq. in. This is an extreme case.

Dead load, however, is not the only factor that must be considered in the design of masonry structures. Wind and other live loads may cause a large increase in the loading on certain parts of the foundation. The load in a masonry wall is probably never uniformly distributed over the individual members of the different courses because of uneven bedding, and the stresses due to loads may be augmented by expansion and contraction of the stone, expansion of water in the pores while freezing, and vibration in structures such as bridge piers. Furthermore, the strength of masonry is influenced by the kind of mortar used. The highest class of masonry, known as ashlar, laid in Portland cement mortar, is not loaded in excess of 500 lbs. per sq. in. This is well within the compressive strength of stone used in building construction and the foregoing statements show the reason why strength is not considered in the selection of stone for this purpose.

Transportation charges effect the cost of stone because of its weight. A block of granite 2 by 2 by 3 ft. weighs a ton.

Fashion also is frequently an important consideration in the employment of stone in building. Considerable demand for California travertine was created in the San Francisco Bay region by the

use of artificial travertine in the construction of buildings at the Panama-Pacific International Exposition at San Francisco. The use of a particular decorative stone in the construction of homes for prominent people will influence others in the selection of a similar building stone.

Appearance and cost aside from durability are the considerations given weight by the architect. There is considerable difference in the appearance of the dark colored, somber igneous rocks such as diorite and gabbro, and the light, pleasing colors of most limestones and granites.

Durability is the most important consideration and in the case of an untried stone its determination is quite uncertain. The durability of stones in use, however, can be readily judged by careful inspection. Stone to be used in steps, floors and other pavements, since it is to be subjected to abrasion, should be one that shows greatest endurance under such conditions. Frequently stone is required to withstand the abrading action of water-borne sand, as in bridge piers, and air-blown sand, as in structures in certain arid regions, and must be tested for endurance under those special conditions.

The Mineral Constituents of Rocks: Read Article 252; it is of interest in connection with the subject of stone but it is not of such importance that the details should be remembered.

Classes of Rocks: Study Article 253. Be able to classify rocks according to geographical origin. Other classifications are

used; on the basis of texture and structure, mineralogical composition, chemical composition, and geological age.

Important Building Stones: Study Article 254 to 260 inclusive. Suitable stones for structural purposes are widely distributed; the principal classes include granite, limestone, sandstone, marble, and slate. The following table gives the approximate production of the different classes of stone during 1919. It was prepared from the U.S.G.S. report, "STONE IN 1919" by Loughlin and Coons.

PRODUCTION IN THOUSANDS OF TONS

	Granite	Basalt (Trap)	Limestone	Sandstone	Marble
Building stone	304	30	394	150	85
Monumental stone	305	--	---	---	95
Paving stone	364	1	---	20	--
Curbing	50	--	7	92	---
Rubble	98	80	328	92	--
Riprap	379	231	833	214	--
Crushed stone	2,700	7,053	21,760	1,180	--
Other uses	20	14	26,400	790	153
TOTALS,	4,220	7,409	49,722	2,538	333

It is interesting to note that the proportion of cut stone used for structural purposes is only a small (about 11%) part of the total production. The principal use for limestone is as a flux in the manufacture of pig iron. See Article 580 page 537 in the text.

Granite: While granite is one of the principal building stones its greatest single use is for crushed stone. Vermont leads in the

production with Massachusetts, Maine, and New Hampshire closely following. Minnesota and Wisconsin rank with the New England States in the production of granite while California leads the Western States.

Granite is quarried in about ten counties in California. The principal quarry, which is controlled by the Raymond Granite Company is at Knowles, Madera County. About a quarter of a million cubic feet of stone have already been removed from this quarry. The stone is a very fine-grained light granite. Many important structures in California have been built with Raymond granite. Among them are: the Municipal Auditorium, the Post Office, the Sub-Treasury Building, the Bank of California, and the Fairmont Hotel in San Francisco; California Hall, the Doe Library, Wheeler Hall, Hearst Mining Building, Boalt Hall, Sather Gate, and the Sather Tower of the University of California at Berkeley; the Time Building, and Citizens National Bank Building in Los Angeles.

Granite is an ideal building stone. It is durable yet not too hard. It is interesting to note that in the recent addition to the Anglo and London Paris National Bank in San Francisco, solid granite columns were used. They were 4½ ft. in diameter and 22ft. long and weighed about 20 tons. It took about three months to shape each column.

Limestone: While limestone is one of the principal building stones most of the production is used for other purposes. As already mentioned it is used for a flux in the production of pig

iron and for various industrial uses. It is also used in the manufacture of portland cement (Article 339, page 310), and in the manufacture of lime (Article 379). More limestone is pulverized and used to improve soil than is used for structural purposes. Limestone is also used as a filler for asphalt, paint, rubber, soap, and other materials. It is quarried in about 20 counties in California. At present the principal use for this product is for macadam roads and concrete aggregate. Indiana leads in the production of limestone for building purposes. The best known and most widely used American limestone is the Bedford limestone which is quarried at Bedford, Indiana, and Bowling Green, Kentucky.

Marble: is a crystalline limestone. It is quarried in about six counties in California.

Travertine is a compact fine-grained limestone deposited on the surface by the water of springs or streams holding lime in solution. The Roman palaces of the period of Augustus were made of travertine quarried at Tivoli near Rome. A quarry at Fairfield, California, supplies an excellent grade of travertine. The bench at the foot of the Sather Tower on the campus of the University of California at Berkeley is made of travertine from the Fairfield quarry.

Sandstone: Sandstone is composed of sand grains cemented together to form a solid rock. The strength and durability depends upon the cementing material. Sandstone is quarried in about seven counties in California. A large number of the buildings at Stanford University are built of sandstone. The St. Francis Hotel

and the Flood Building in San Francisco are made of Colusa sandstone. A large part of the sandstone quarried is known as quartzite (ganister) and is used for making silica brick, for furnace lining (see Article 592 on page 548 of the text).

Trap: Trap is a designation (not used by the geologist) which includes fine-grained basic rocks such as basalt, diabase, and gabbro. These rocks usually occur in columnar structure and present a stepped appearance. The Swedish word "trappe" means stairs; therefore, trap has reference to the occurence of the rock in the quarry. Trap is tough and strong (stronger than granite) but it does not weather well. It is hard to quarry and is used principally for paving blocks and crushed stone.

Slate: The most valuable characteristic of slate is its tendency to split into thin sheets, leaving smooth plane surfaces. Slate does not absorb water, posses considerable toughness and strength, and is moreover a good insulator for electric current. Its structural use is confined to roofing.

Durability of stone: Read Articles 261 to 266 inclusive. Frost is probably the most destructive agent for stone when it is exposed to the weather. Many varieties of stone show signs of disintergration after a few years of such exposure. The estimated life of stone under exposure varies from12 years for soft sandstone to several centuries for hard granites. Study Article 261 in the text on the weathering of stone. Atmospheric conditions affect the durability of stone. The Egyptian Obelisk commonly known as

Cleopatra's Needle, was built about 1500 B.C. For over 3000 years it stood unharmed in the mild Egyptian atmosphere. When it was brought to New York in 1879, immediate steps had to be taken to save it from the ravages of our American climate by giving it a surface coating. See the third paragraph of Article 262 in the text. Limestone and sandstone are not in general very durable and many examples of their rapid disintegration might be cited. There are, however, very durable varieties of both these stones.

Preservative coatings are effective in preventing the absorption of water and protecting the surface of the stone but they do not last long and must be frequently renewed.

Durability tests for stone: The most reliable test is the examination of exposed quarry ledges or cut stone that has been exposed to the weather. The action of destructive agents may be closely imitated in the laboratory but data on the actual durability are not thus obtained and the interpretation of laboratory results is therefore, quite difficult. The freezing and thawing test, and the acid test are the principal laboratory tests for durability. The absorption test is of value in determining the probable effect of weathering. The more water a stone absorbs, other things being equal, the more softening and harm will be done by atmospheric acids.

The heat occasioned by fires in large buildings often exceeds 1500 degrees Fahrenheit. No stone will withstand this. Limestone is decomposed at about 1200 degrees Fahrenheit and granite spalls

and cracks at these high temperatures. Quenching intensifies the effects of fire. Clay products, brick and terra cotta, are superior to stone in their resistance to the effects of fire.

The Physical properties of stone: Read Articles 267 to 270 inclusive. The coefficient of thermal expansion is not constant as in the case of metals. It increases with an increase in temperature. An average value is .000004 inches per inch per degree Fahrenheit. Stone once heated does not return to its original dimensions when cooled. This permanent expansion is mentioned in Article 267; it is important. Stone slabs, particularly those of marble, frequently warp when exposed to the weather. Since marble is formed by a process of slow deposition, and it is estimated that the formation of one inch took about a thousand years, it is reasonable to suppose that the stone is not uniform in structure perpendicular to its bedding plane. Different layers may have different thermal properties which would cause variable permanent sets under heating and cooling, sufficient at least to produce warping. The surface of a stone monument exposed to the direct rays of the sun may easily exceed 120 degrees Fahrenheit. Marble slabs and shafts in cemetaries are frequently warped. Recent tests show that concrete road slabs warp, but not permanently, due to differences in temperature of the upper and lower surfaces. During the day the slab is concave downward and at night when the air is cooler than the ground it is concave upward so the the edges are actually lifted off the subgrade.

To remember the approximate specific weight of stone, take the weight of granite, about 170 lbs. per cu. ft. Trap rocks weigh more and the other building stones weigh a little less.

Mechanical properties of stone: Study Articles 271 to 273 inclusive. The strength of stone is rarely developed except in lintels and top-slabs for culverts where the stone is used as a beam. The compression test is frequently the only test made but the transverse test, which gives the modulus of rupture and the modulus of elasticity, is also made. In your study of a new material make a table with average values to compare it with some material you have already examined.

Average Ultimate Strength, lb. per sq. in.

	Compression	Modulus of Rupture,	Modulus of Elasticity
Granite	20,000	1,500	8,000,000
Limestone	9,000	1,200	8,000,000
Douglas Fir (air dry)	Parallel to the grain. 7,000 / Perpendicular to the grain. 900	10,000	1,500,000

The above values are from tests on small test specimens. Remember that although average sandstone is stronger than average limestone, a good limestone is stronger than a poor sandstone. Tests of stone are always made on overn dry specimens. Soaking decreases the strength of stone, a fact which has been noticed in tests of marble.

Stone, like other brittle materials such as cast iron and concrete, does not obey Hooke's law. The stress-deformation curves, instead of being straight, to the proportional limit, are concave upward - see Figures 2, 3, 4, and 5 on pages 256 and 257 in the text.

Stone is used in the construction of various types of roads, from the block or cobblestone pavements, to the bituminous macadam, cement concrete, and the water bound macadam pavements. The characteristics of the stone used depend upon the type of pavement and the character of the traffic. In the case of stone for road pavements as well as in the case of building stone, the crushing strength is of secondary importance, while toughness, hardness and resistance to wear are of the most importance. Tests to determine each of these properties have been standardized by the United States Bureau of Public Roads and the American Society for Testing Materials. They also publish requirements to guide in the selection of available material.

The specifications for crushed stone for concrete aggregate are rather general. They usually state that any durable crushed stone or any clean, hard gravel not subject to ready disintegration may be used.

Stone quarrying: Blocks of stone are removed from the quarry-ledge by blasting or hand tools. Early Egyptians cut grooves in the rockledge with crude bronze picks. Dry wooden wedges were

pounded into the grooves and soaked with water. The expansive force produced by the swelling of the wood forced out the block of stone. Hand methods at the present time require the use of a steel drill to make a series of holes in the rock into which steel wedges are driven to force the rock apart. Power operated drills and channelers with the use of explosives are replacing hand methods. Power-driven saws, planers and lathes are used to shape the blocks of rough stone.

Stone masonry: There are three classes of stone masonry - riprap, rubble and cut-stone. Riprap is uncut stones piled up to form masonry. It is used for low walls and to protect stream banks from erosion. Rubble is riprap with stones held together with mortar. Cut or squared stones laid-up with mortar produce the highest class of masonry. The term ashlar is applied to masonry of the last class, when the joints are not more than $\frac{1}{2}$ inch thick. This requirement can be met only by having plane surfaces on individual stones. This construction insures uniform distribution of loads, so that the highest loads are allowed on ashlar masonry.

The strength of stone masonry depends largely on the strength of the mortar used and the thickness of the joints between adjacent stones.

Riprap is not meant to carry loads. Rubble in lime mortar with individual stones placed at random, is designed for 60 lbs. per sq. in., while the allowable load on ashlar masonry made of granite in portland cement mortar is 600 lbs. per sq. in.

QUESTIONS:

1. If granite weighs 170 lbs. per cu. ft. what is its apparent specific gravity?

2. Which beam will support the greatest load; one of granite or a wooden beam (Douglas Fir) of the same dimensions, span and condition of loading?

3. Which of the beams mentioned in question 2 will deflect the most under a given load? Why?

4. What are the requirements for a good building stone?

5. What are the principal building stones?

6. How is the durability of stone determined?

7. What is ashlar masonry?

8. What is the allowable load on ashlar masonry?

9. Draw a typical stress-deformation curve for stone.

10. How do you account for the warping of marble slabs which have been exposed to the weather?

UNIVERSITY OF CALIFORNIA EXTENSION DIVISION

Correspondence Courses

Materials of Engineering Construction

Civil Engr-8 Assignment 8 Prof. C. T. Wiskocil

STRUCTURAL CLAY PRODUCTS

Introduction: Clay products are widely used in engineering construction. The material itself is not used in its natural state, as stone and wood are used, but is first manufactured into various products. This is a simple process because moist clay, which is very plastic, can be molded into the desired form and then easily converted into a stone-like mass by firing or burning. Burnt-clay is, then, the actual material used in engineering construction. It is one of the most durable materials as is proved by the good state of preservation of specimens found in ancient ruins. It has been used since earliest times. Clay pipe found on the Island of Crete dates back, according to one record, to 5,000 B.C. Other records show that clay products were used in 2247 B.C. and in the book of Genesis we read that the Israelites made bricks from mud of the river Nile.

Brick, the principal clay product, has been used for many types of structures. Parts of the Great Wall of China, 211 B.C., were made of brick. J. A. L. Waddell reports in "FOLLOWING THE GREAT WALL OF CHINA" (Engineering News-Record, 88, 642, April 20, 1922), that the bricked wall is still in a fair state of preservation. London was rebuilt with brick after the fire of 1666 A.D. The first brick house in America, built in 1634 in Medford, Massachusetts, by

Gov. Craddock of the Massachusetts Bay Colony, was made with bricks brought from Europe. Independence Hall, Philadelphia, and the famous old State House of Boston were built with brick. The first brick pavement in the United States was laid in 1871 in Charlestown, West Virginia. At Great Falls, Montana, the Boston and Montana Copper Company erected what is probably the tallest brick chimney in the world. It is 506 feet high and 50 feet across the top.

Read Article 274. Remember the classification of structural clay products as given in this paragraph. Clay suitable for the manufacture of ordinary building brick occurs in large deposits in many localities. Special grades of clay are required for the making of paving brick, fire bricks, terra cotta, and chemical stoneware.

The following table gives the approximate distribution of the clay products made in the United States:

Product	Percentage of Total Production
Common brick	20
Fire brick	18
Sewer pipe	8
Hollow tile	6
Drain tile	5
Paving brick	5
Face brick	4
Tile (not drain)	3
Arch. Terra Cotta	3
Other products	5
Pottery	23

Raw materials used in the manufacture of clay products: Study Articles 275 and 276; they describe the various classes of clays in common use and give the composition of clays. Notice that clay,

shale, and slate differ only in degree of consolidation and that the principal elements are silica, alumina and iron oxide.

Pure clay is hydrated aluminum silicate (kaolin) and is pure white. It is produced by the weathering of pure feldspar, a group of mineral substances consisting of silicates of alumina, potash, soda and lime. Potash feldspar is known as orthoclase.

Common clays are formed by the weathering of igneous rocks and clayey limestones. They contain iron oxide, lime and magnesia.

Chemical action is not necessary in the disintergration of rocks; weathering washes out some of the silica, as in the case of the weathering of feldspars.

Soda, potash, lime, magnesia, and ferrous oxide combine with silica and form fusible compounds which act as fluxes. If they are absent the burnt clay is porous. If they are present in sufficient quantities, the granules of clay are fused and a vitrified product is formed.

Article 275 divides clays according to the geological manner of formation into residual, sedimentary and glacial clays. All classes are used for brick making but the sedimentary clays are most frequently found satisfactory. Sedimentary clays may be marine clays, lacustrine, flood-plain, or estuarine clays. The marine clays yield the most satisfactory material for the manufacture of brick. In this class are the white-burning clays - ball clays and kaolins - also fire clays and impure clays and shales.

The following table gives a typical distribution of clays sold annually in the United States. The figures are in tons. The clays sold are estimated to be only a small proportion of the total amount mined. The table is interesting, nevertheless, since it gives the commercial names of the various clays and shows the uses to which clay is put other than for structural purposes.

Kaolin	32
Paper clay	174
Slip clay	17
Ball clay	107
Fire clay	2,348
Stoneware clay	81
Brick clay	94
Miscellaneous	260

Clay available for the manufacture of clay products is one of the most widely distributed minerals. Hence there are clay-working plants in every State in the United States. The manufacturers who use low-grade clays usually mine their own raw material but the percentage of manufacturers mining their own clay decreases as the use of a higher-grade clay is employed. Nearly every manufacturer who makes the highest-grade ware buys the clay he uses.

Kaolin, the purest form of clay, is produced principally in the Southern States. It is used mostly in the manufacture of china, white ware, such as semiporcelain, and semivitreous porcelain ware. Some is used also for fire brick and in the manufacture of paper.

Paper clay, as the name indicates, is used principally in the paper mills for a filler and coating for paper. A large part of this clay sold is used for the purposes listed under kaolin, and

also in the production of pottery and tile. About six percent of the paper clay sold is used by the cement mills in the manufacture of white cement. This clay is also used in the manufacture of oil cloth and phonograph records and paint filler and pigment. Georgia, North Carolina, and Illinois are the principal producers of paper clay.

Slip clay is an easily fusible material. Its chief use is in the manufacture of artificial abrasives, such as emery wheels, and for glazing. Slips are applied to architectural terra cotta and pottery to give the product an impervious surface. Ohio and Michigan are the principal producers of slip clay.

The principal use for ball clay, which is a plastic white-burning clay, is for white-ware, such as high-grade pottery and tile, porcelain electrical supplies and sanitary ware. Most of the supply comes from Tennessee and Kentucky.

Fire clay finds its greatest use in the manufacture of refactory products. It is used for fire brick, converter and cupola linings (in the steel industry), and in the manufacture of terra cotta. These are however, only the principal uses; there are many others. This type of clay is probably used for more different purposes than any other. It is mined in 32 states, Pennsylvania and Missouri producing the greatest amounts. See the note on fire-clay in Article 275 in the text.

Stoneware clay is refactory or semirefractory and is used chiefly in the manufacture of stoneware and chemical stoneware.

Lower-grade clays are used in the manufacture of building and paving brick, drain tile, sewer pipe, and fireproofing. Almost all of the manufacturers of these products mine their own clay.

Read Article 277 carefully. It gives the physical properties of raw clay and the relation of these properties to those of the burnt-product. Plasticity is an important physical property. The necessity for a certain degree of plasticity is evident to anyone who has ever attempted to work wetted clay. Most of us are not familiar with clay working methods; yet even those who are have often wondered wherein the hardship for the Israelites lay when they were forced by Pharoah's taskmasters, according to the Bible story, to make bricks without straw. Some have thought that the straw was added to the clay as a binder just as hair is added to plaster; but because of the weakness of the straw fiber this is not an adequate explanation. No more satisfactory explanation was offered until Dr. E. G. Acheson, the discoverer of carborundum, found in his experiments that the plasticity of clay was increased by additions of dilute solutions of tannic acid. Moreover the strength of the dried clay was greatly increased. Although straw does not contain tannic acid it was found that the water-extract of straw was just as effective as were solutions of tannic in increasing the plasticity and strength of clay.

Excessive shrinkage of clay is undesirable, but a small amount, about 8%, aids in making a more compact material.

Manufacture of clay products: The method of manufacture is approximately the same for all classes of clay products. Study the steps in the process as given in detail in Articles 278 to 286 inclusive.

Any clay which possesses a sufficient plasticity for molding and which will burn to the proper hardness is used in the manufacture of bricks. Usually impure clays are employed and they require special treatment as described in Article 278.

The molding processes are described in Article 279. A small proportion of common brick is still made by hand methods. There are two methods of hand molding, slop-molding and sand-molding. In the former, water is used to prevent the clay from adhering to to the mold and in the latter method the same result is accomplished by the use of sand. Hand made brick is the lowest grade of brick. Machine-made brick is made by three methods, soft-mud, stiff-mud, and dry-press. The process used depends upon the characteristics of the clay employed and the class and quality of brick desired.

Artificial methods of drying clay products, as described in Article 280 are coming into general use in the manufacture of brick. Higher grade products are seldom dried any other way.

The two classes of kilns, the intermittent and continuous, are described in Article 281. The intermittent kiln consists of two types, the up-draught and down-draught kilns. The down-draught principle is used in the continuous kiln. The old scove kiln, which is essentially an up-draught kiln, is still common in small

yards where the hand process of molding brick is used. The down-draught kiln is more efficient than the up-draught; and it burns very evenly terra cotta and pottery, as well as brick. The continuous type of kiln is more economical than any other but it is more expensive to install.

The heating of clay, which is necessary to give it its maximum strength and hardness, is known as firing or burning. The process is described in detail in Article 282. The firing of a scove kiln usually takes about a week.

Read Article 283; It will be referred to when terra cotta and sewer pipe are discussed.

The degree of burning of light-colored ware, in a normally operated kiln, can be quite accurately estimated by the color of the product if the characteristics of the clay are known. Flashing, however, (see Article 285) makes it difficult to judge the degree of burning by means of the final color of the ware.

Annealing is of highest importance in the manufacture of all clay products. After the ware has been properly burned the temperature of the kiln is reduced at a slow, uniform rate until that of the surrounding astmosphere is reached; the ware is then removed.

When the ware is removed from the kiln it is sorted according to quality, which is determined by the degree of burning, and the freedom from such imperfections as excessive warping, cracks, and deep kiln-marks. There is a special market for inferior products.

Tests of structural clay products: Study Articles 287 to 296 inclusive and read Appendix A, pages 807 to 814 inclusive. Be able to list the two classes of tests, those made on the job and those made in the laboratory.

Examination of appearance in the strict sense is not a test, it is visual inspection. Intelligent physical inspection, with the hammer and hardness tests, are often sufficient to determine the acceptability of structural clay products. In order to determine mechanical properties and the effect of changes in materials or methods of manufacture it is necessary to have more elaborate tests made. The transverse test, described in Article 300, is the most important test made on building brick. It is also used for paving brick. The compression tests are made on brick of all kinds and on various other clay products such as hollow building tile and clay pipe. The methods for making the pipe tests are shown in Article 293. In addition to these tests, pipe is also tested for its resistance to internal pressure. Single lengths, and often several lengths put together are subjected to hydrostatic pressure. The rattler test described in detail in Appendix A is still the standard abrasion test for paving bricks. Tests of this character are intended to imitate the conditions under which the product is to be used. In spite of the fact that the rattler test does not fulfil these requirements it has been in use for some time. The test described in Article 295 has never been standardized and accepted by the American Society for Testing Materials. In all

testing, as described in the case of the alternate freezing and thawing test in Article 296, the conditions of actual testing should be standardized so that the results of different laboratories and tests made at different times will be comparable. Differences in the shape and size of the test specimen, rate and manner of applying the load and method of general procedure all affect the results of the test.

Building Brick: Read the text, Articles 297 to 303 inclusive, on the subject of building brick.

The manufacture of clay products has already been described, and specific information on brick has been given. Article 297 emphasizes some statements previously made. Bricks after being molded are dried for a period varying from several hours to several days depending upon the method of molding and drying. After drying they are burned in a kiln for about a week, the temperature of the bricks being very gradually raised. The cooling process takes place gradually over a period of several days.

Brick may be classified, as stated in Article 298, according to method of molding, degree of burning, form and use. In general all bricks have the same proportions: the width of two bricks plus a mortar joint will equal the length. When used in the facing of masonry, bricks must have true surfaces and sharp edges. Face bricks are pressed or repressed before firing in order to insure these necessary qualities. Glazed brick are made by coating one side of the unburned common brick with a slip clay of the desired color over which a second coat of transparent glaze is applied.

These coatings fuse into the brick in the burning process. Enameled brick are made of a higher-grade clay. In the burning it fuses and unites with the body of the brick. The enamel, which usually contains an oxide of tin is applied to the unburned or to the finished brick. Glazed and enameled bricks are used for building courts and interior finish. Tapestry brick, the peculiar surface of which is formed by cutting off a thin slice by a wire, is also used as a face brick.

Study the requirements of good building brick listed in Article 299. This is an important article. The first paragraph in this article mentions effloresceence. It is a surface discoloration, usually white, but occasionally green or yellow, formed by the leaching out of soluble salts from the interior of the brick, and the depositing of these on the surface by the evaporation of the water. Besides being unsightly this process is liable to disintegrate the brick. Efflorescence can be prevented by using water and clay free from the soluble salts of magnesium, sodium, and potassium. If this cannot be done, an effective method of prevention is the preliminary treatment of the raw materials with barium salts to convert the soluble salts, which usually exist as sulphates, into the insoluble barium sulphate. Careful, rapid drying of the molded brick to prevent the salts from coming near to the surface and hard burning to volatilize the alkalies and to make a dense brick both help to prevent efflorescence. After the brick are in place efflorescence can be prevented only by keeping

the brick dry. Defective drain-spouts often saturate the surrounding brick; the source of water should be removed, as efflorescence is likely to result. Brick can be kept dry by surface coatings of waterproofing material such as paraffin.

Tests of brick are given in Article 300. Look over the tables given on pages 282 and 283; note the variation for the same class of bricks. Determine average values to compare with similar data already obtained for the materials you have studied. Take good building brick; assign an average compressive strength of 4,000 lbs. per sq. in., an average modulus of rupture of 1000 lbs. per sq. in. and an average modulus of elasticity of 6 million lbs. per sq. in. The strength of brick masonry, just as in the case of stone masonry, is much less than the strength of its component parts. The compressive and tensile strength of individual bricks is of relative value in the comparison of different kinds of brick. The fractured surface of the brick in the transverse test affords an opportunity to observe the texture and uniformity of structure. The stress-deformation curves are similar to those of cast iron and concrete - also brittle materials - and usually are not as straight as indicated in Figure 6 on page 284. The modulus of elasticity, therefore, is not uniform but decreases with increasing loads.

Brick Masonry: At the time brick was made by hand (the first power-operated machinery being used about 1840), stone made the highest-grade masonry. At present, however, with a large variety

of high-grade bricks available, brick masonry compares well with the best grade of stone masonry. Well made masonry of good brick is as nearly permanent as any structural material. Brick masonry is more resistant to fire, more easily built, and usually cheaper than stone masonry.

Mortar is an important factor in the construction of masonry. Its principal function is to form a bedment and to hold the bricks together. The influence of the joint upon the color of the brickwork can be understood when consideration is given to the fact that the mortar joint constitutes from 1/10 to 1/5 of the surface of the finished wall. The mortar also adds effectiveness to the appearance of the bond, which is the term used for the brickwork patterns or relative position of the faces and heads of the bricks as laid. Mortar is made of lime and sand, cement and sand, or a combination of lime, cement, and sand.

1. The kind of mortar has an important effect upon the strength of brick masonry. 2. Lime mortar is not as strong as cement mortar. 3. The strength of masonry is proportional to the transverse strength of the bricks used in its construction. Mortar joints should be as thin as possible and of uniform thickness. Regularity in the shape of the bricks is essential. 4. Since the initial failure of brick masonry is caused by a transverse failure of individual bricks the ultimate strength of this type of construction can be increased by laying the bricks on edge instead of flat or by using bricks of more than ordinary thickness.

Sand Lime Brick: Study Articles 304 to 307 inclusive. A sand lime brick is not a burnt clay product but it is used for the same purposes and has the same size and shape as a clay brick. The sand-lime brick consists of about 90% sand and 10% lime. About 85% of the sand is retained on a 100-mesh sieve and constitutes the aggregates, which are bound together by a calcium-silicate. This binding material is formed by a chemical combination of the lime and part of the sand which passes the 100-mesh sieve.

The bricks have fairly high strength when they are removed from the hardening cylinder and it increases for some months after they have been made. Their ultimate strength is about three-fourths that of good building brick.

Paving Brick: Study Articles 308 to 310 inclusive. Paving bricks differ from building bricks in several ways. The selection of suitable clay is more limited, shale being usually employed. The burning temperature is higher because it is necessary to bring the clay to the point of actual vitrification so as to secure the proper hardness in the finished brick. The prevailing size of paving bricks is 3 by 4 by 8-1/2 inches. For maximum toughness the annealing period should be about 10 days as stated in Article 285. Only the properly vitrified bricks make satisfactory paving material; the overburned bricks are used for foundations and for sewer construction while the underburned bricks make and excellent building brick. Average values for compressive strength are 10,000 lbs. per sq. in.; for transverse strength use 2,000 lbs.

per sq. in. and 6,000,000 lbs. per sq. in. for the modulus of elasticity. Remember that the maximum permissible loss in the rattler test is 28%, and that the bricks must be dry when tested. The abrasion loss of wet bricks or bricks saturated with bituminous materials is greatly reduced.

Refactory Brick: Study Articles 311 to 315 inclusive, Refactory bricks are capable of withstanding the effects of high temperatures. There are three classes of refactory bricks: acid, basic, and neutral. All are burned at a high temperature. The principal use of these bricks is in the steel industry where the type of brick selected depends upon the process of steel manufacture, whether acid, basic or neutral.

Hollow Building Blocks: Study Article 316. These blocks, which are often referred to as hollow tile, develop their greatest strength when laid on end. The material resembles ordinary hard burned brick. The average compressive strength of well burned tiles is 7,000 lb. per sq. in. with a modulus of elasticity of about 4,000,000 lb. per sq. in. The strength of light-burned tiles is about 30% lower.

Read Article 317 on the strength of hollow tile columns; it is not very important.

Read Articles 318, 319 and 320 on roofing tile, and floor and wall tile. Roofing tile is usually made of terra cotta and burned at a high temperature to insure hardness and low absorption. Tile makes a very durable but rather heavy roofing material.

Terra Cotta: Read Articles 321 and 322. Terra cotta lumber is not extensively used. Architectural terra cotta, however, is one of the standard building materials. Permanent buildings faced with terra cotta are made in the United States, Australia, Japan, and South America and the material is not thought of as a substitute or an imitation of stone. Terra cotta requires considerable strength and accuracy in the finished ware, therefore, clays of appropriate composition are limited and must be carefully selected. Clays forming the body of the ware are mixed for both chemical and mechanical reasons. Plaster of Paris molds are taken from plaster of Paris models. These molds have to be specially made to provide for the shrinkage that normally occurs in drying and burning. A mold withstands the wear of from 20 to 50 pressings according to size. In the pressing shop the molds are faced with from 1 to 2 inches of clay and partitions about 1 inch in thickness are formed which leave spaces or cells of about six inches square. The partitions are built up to reinforce and strengthen the unit. The piece is then turned out on the drying boards where it is retouched, After drying, the piece passes before the sprayers where the surface glaze, finish, slip, or color is applied by an atomizer with compressed air. In burning, the ware is piled in muffle kilns on fire-brick posts and slabs so that each piece is free from any extra weight. The burning temperature is about 2,200 degrees Fahrenheit.

Almost any color tone can be had in terra cotta, from the pure white through the cream and buff shades into the greys. The texture ranges from the natural clay and the smooth or honed

finish through different degrees of tooling, dragging, and stippling to any degree of desired roughness. The surface is made impervious with a slip, varying through matt or dull to lustrous and brilliant glazes. The use of color or polychrome in terra cotta is being applied to both interior and exterior decoration.

There are many examples of the use of terra cotta in building construction in California. The Fireman's Fund Insurance Building in San Francisco and the Yolo County Courthouse in Woodland are particularly good ones. Others are the Golden Gate Valley Branch of the San Francisco Public Library, the Hobart Building and the trim on the Southern Pacific Building in San Francisco; the Bank of Italy in Fresno; the Northern California Bank of Savings in Marysville; the First National Bank in Santa Maria; and the Farmers and Merchants National Bank in Stockton. Then there are notable examples in buildings in the large cities in the United States; such as the Woolworth Building, the Hudson Terminal Buildings, the Produce Exchange and the World Building in New York City. Terra cotta is well adapted to interior facings, as is shown in the United States Post Office at Pasadena, California.

Study Articles 323, 324 and 325 on sewer pipe, drain tile, and conduit. Sewer pipe is usually made with socket ends, referred to as bell ends in the text, and the joints are made tight by the use of cement mortar. Sewer pipes, while often spoken of as vitrified pipes, are not actually vitrified. The salt-glaze generally used gives them the appearance of a vitrified product. Common salt (sodium chloride) is thrown on the kiln fires. It volatilizes

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and the sodium vapors react with the clay and form a fusible sodium-aluminum-silicate which covers the surface with a glaze. This glaze is very thin and is not as effective as vitrification in reducing "Sweating" of pipes under hydrostatic pressure tests. Salt glazed pipe is much cheaper than a vitrified pipe would be. There is considerable loss in the manufacture of this product because of warping and distortion in the drying and firing processes.

Drain tile is a cheaper product. It is fired at a lower temperature and is not very dense. No attempt is made to make the material porous because the water enters the pipe through the joints and not through the walls of the pipe.

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QUESTIONS:

1. Classify clays according to geological formation.
2. What can be considered a good brick?
3. Could a brick be satisfactory for one purpose and unsuited for another?
4. What bricks are made in your locality? which are preferred and why?
5. How does sewer pipe differ from drain tile?
6. How are sand-lime bricks made?
7. What is efflorescence? Can it be prevented?
8. How is architectural terra cotta made?
9. Give the average compressive strength, transverse strength, and modulus of elasticity of building bricks and paving bricks.
10. How does the strength of brick masonry compare with that of the individual brick used in its construction?

UNIVERSITY OF CALIFORNIA EXTENSION DIVISION

Correspondence Courses

Materials of Engineering Construction

Civil Engr-8.A. Assignment 9. Professor C. T. Wiskocil

PORTLAND CEMENT

Introduction:- The cementing materials used in engineering construction are classified in Article 326. Portland cement is not only the most important of these materials but it ranks as one of the principal structural materials.

Portland cement is a grey powder (some white Portland cement is made) which when mixed with water to form a paste has the property of hardening into a stone-like mass whether in air or under water. Its property of hardening under water together with the fact that it develops considerable compressive strength gives Portland cement a wide variety of uses it would not otherwise have. It is rarely used neat, that is, as a mixture of cement and water. Neat cement is too expensive and besides it is subject to excessive shrinkage. Cement is usually mixed with an inert material. If this inert material is sand, the resulting mixture is called mortar; if larger broken stone or gravel is used with the sand, the mixture is known as concrete. In both cases the cement paste is the binding material. Mortar is used in the fabrication of stone, brick and terra cotta masonry; where used for surfacing interior and exterior walls, it is called plaster or stucco. As concrete it is poured into molds to form monolithic structures such as foundations, walls, dams and all types of pavements. When steel is placed in concrete to take

tensile stresses the product is known as reinforced concrete. Proper reinforcement makes it possible to use concrete for practically every type of engineering structure, such as complete buildings, from the foundation through the columns, beams, floor slabs, and walls, to the roof; and as bridges, reservoirs, arches, chimneys, and even ocean-going ships. Read Article 326 in the text.

Definition:- While portland cement is only an artificial mixture of calcareous (which means lime bearing), and argillaceous (which means clayey) materials, burned to a clinker at a temperature of incipient fusion and afterward ground to a fine powder. It is well to know the definition given in Article 327 because many times a verbatim repetition is required.

Incipient fusion is the stage at which fusion is just about to occur. It is sometimes spoken of as initial fusion.

Characteristics of portland cement:- Study Article 328. The weight of portland cement is usually taken as 94 lb. per cu. ft. A sack contains a cubic foot and there are four sacks in a barrel.

The chemical elements:- Study Article 329. Remember only average figures; lime 62%, silica 22%, alumina 7%, with the remainder consisting of iron oxide, magnesia, sulphur trioxide, and water.

Proportioning of raw materials:- Read Article 330. The proportioning of the raw materials in making portland cement is not a simple matter. As stated in Article 336 the temperature to which the raw materials are raised is only sufficient to start fusion and consequently complete solutions of all the elements are not obtained.

After calcination the product is not a mixture of clayey and calcareous materials, but is what is often spoken of as a solid solution of the various components consisting principally of silicates and aluminates of lime. While the conclusions of Newberry and Le Chatelier have been shown to be not entirely correct, the methods of proportioning based on their conclusions have produced excellent cement.

Effect of minor constituents:- Read Articles 331 to 335 inclusive. White portland cements contain very little iron oxide. The color of the ordinary portlands is due principally to this oxide of iron. The amounts of carbonic oxide are indicated by the loss on ignition. The specified limits for the loss on ignition of sulphur anhydride and magnesium oxide are given on page 372 in the text.

The consitution of portland cement:- Read Article 336. Portland cement consists of a mechanical mixture of chemical compounds which have constant physical and chemical properties. These compounds are tricalcium silicate ($3\ CaO \cdot SiO_2$), tricalcium aluminate ($3CaO \cdot Al_2O_3$), tricalcium ferrite ($3CaO.Fe_2O_3$) and calcium orthosilicate in the beta form ($2\ CaO.SiO_2$) given in the decreasing order of their cementing qualities. In addition to these compounds there is usually about 3% of gypsum. Magnesia in the form of the oxide (MgO) is in a state of solid solution in the other components, usually in such small quantities that it does not have much effect. Traces of other elements - potassium and sodium and particles of

quartz from the flint pebbles in the ball mills, metallic iron from the machinery and even particles of semi-fused ash, when coal is used as the fuel in calcining the cement,-- are sometimes found in normal portland cements.

The compounds of alumina, lime, and silica have been shown to constitute the bulk of normal portland cement in studies of the ternary and binary systems of the three principal components by technicians (~~chemists~~, physical-chemists, and chemists) of various university laboratories, the Bureau of Standards, and the Geophysical Laboratory. A chemical analysis of a cement does not give the actual composition because the results are in terms of the oxides and the principal elements do not exist in the form of oxides. It is possible, however, to recast an analysis according to known laws of chemical combination and obtain the percentage composition of the cement in terms of the actual compounds that exist instead of the oxides.

Setting and hardening of portland cement:- Study Article 337. The setting and hardening of cement pastes are defined in the first paragraph of this article. When mixed with water the components previously mentioned are hydrated, with the production of amorphous hydrated silicates and aluminates of lime, and considerable calcium hydrate in both crystalline and amorphous forms. The different components do not hydrate with equal ease. It is quite generally agreed that the tricalcium aluminate is the first to hydrate and that this compound affects the initial set. The tricalcium silicate, which has been found to have the greatest cementing value

and to be the best hydraulic component by actual experiment, is next to hydrate. It is this reaction that causes cement to harden. Calcium orthosilicate is the most inactive of the cement components.

Michaelis' colloidal theory of the hardening and setting of portland cement is given in this article. Study this carefully and be able to give it in your own words. It is essentially as follows: The hardness, strength, and durability of cement depend upon the fact that the products of hydration are formed in the non-crystalline colloidal state. Under the microscope, freshly hydrated compounds are non-crystalline and do not crystallize for from 10 to 20 days.

Hydration must begin at the surfaces - grains of cement become coated with colloidal gel which causes them to stick together. The gel is impervious and the centers of the grains are not immediately hydrated. They become hydrated only as water can diffuse through the colloid coating. At this stage the cement is not hard.

The hardening depends upon the drying of the thin coating of colloid which envelopes the grains. It is not necessary that the absorbed water in the colloid coating evaporate (some does when the cement sets in air). The free water may be taken up by the unhydrated centers of the grains and converted into combined water. Here it cannot manifest itself as water. (Crystals containing more than half their weight in water, in the form of water of crystallization,

do not appear to be wet). It is not difficult to understand that cement gel can dry out in this manner even under water. Water cannot readily pass from grain to grain because of the impervious coating of colloid. The grain centers use up free water faster than it can be supplied from the outside and the gel becomes dry and hard. It is an irreversible colloid and therefore remains hard.

Historical notes:- Read Article 338 on the growth and importance of the portland cement industry.

Some knowledge of cements, similar to portland, which set under water, was possesed by the Romans. It is said that the base of the Temple of Castor and Pollux in the Roman Forum was a solid mass of puzzolana concrete.

The first impetus was given to hydraulic cements by John Smeaton who rebuilt the lighthouse on Eddystone Rock in 1756. See Article 387 on page 365 in the text.

About fifty years later the French chemist Vicat produced a product similar to that used by Smeaton. Vicat's cement was produced by burning a finely pulverized chalk and clay after he had mixed them to form a paste.

The first patent was granted in 1824 to Aspdin, a Yorkshire bricklayer, who heated pulverized chalk with clayey river mud. Because of a fancied resemblance (actually there was very little) between his product and a well known limestone quarried near Portland (which is on the South East coast of England) and known as Portland stone, he named it Portland cement. The name has been universally adopted. Aspdin is usually given credit for the invention of portland cement.

In 1874 the first portland cement was made in the United States. In 1920, 100,302,000 barrels were produced at an average cost of $2.01 per barrel.

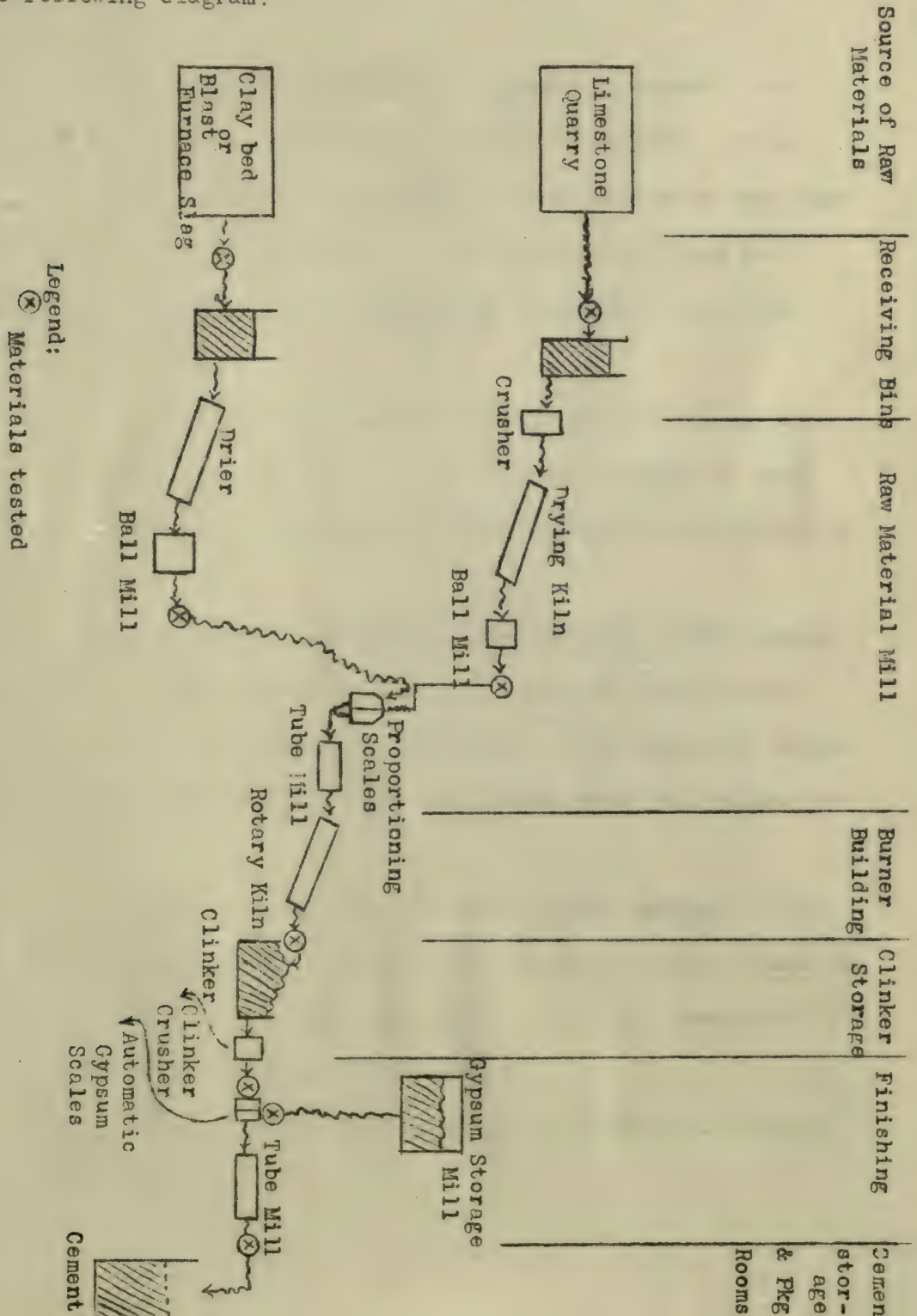
Raw materials:- Read Article 339. Some of the raw materials used by California plants are as follows: The Standard Portland Cement Company at Napa Junction, Napa County uses a pure limestone and a clayey limestone; the California Portland Cement Company at Colton, San Bernardino County, uses clay and a pure limestone; the Cowell Portland Cement Company at Cowell, at the foot of Mount Diablo near Concord, Contra Costa County, uses travertine and shaly clay; the plant of the Santa Cruz Portland Cement Company, at Davenport, just north of Santa Cruz, uses shale and a pure limestone; the Riverside Portland Cement Company operates a plant at Riverside using a mixture of clay and limestone.

Manufacture:- Study Articles 340 to 349 inclusive, they describe the manufacture of portland cement by both wet and dry methods. Most cement manufactured in the United States is made by the so-called dry process. Only one California plant, that at San Juan (just south of Gilroy), making the Old Mission brand, uses the wet method of manufacture. Crude oil is the fuel used in the California cement mills.

The average temperature of burning is about 2,800° Fahrenheit. In most plants the clinker is cooled in air but if it is cooled as stated in Article 345, by being sprayed with water, note that the water does not injure it. Clinker has no cementing properties; it must first be finely ground.

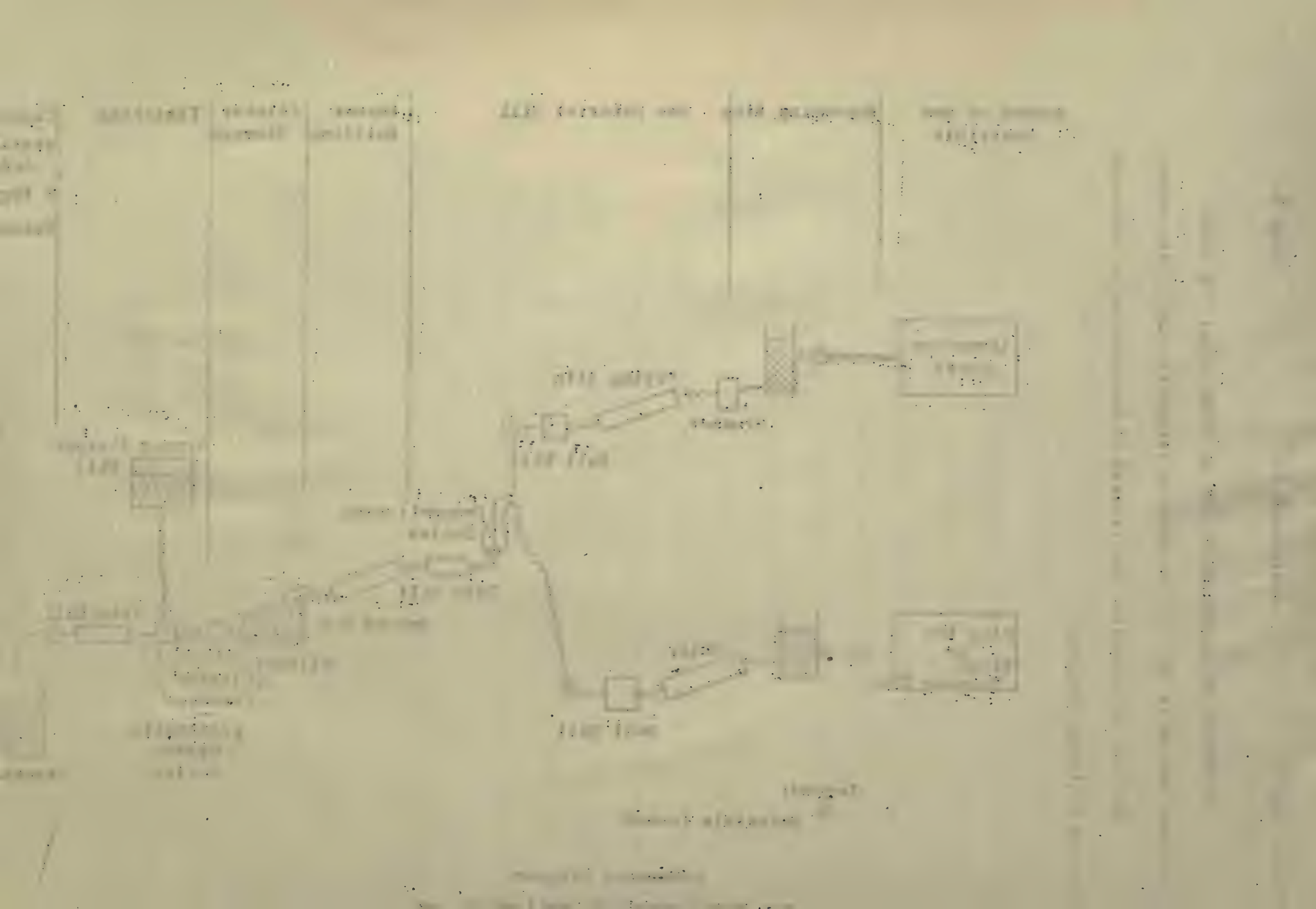
The amount of gypsum which can be added after the cement has been burned is 3%. It is added to retard the set of the cement.

Be able to visualize the process of manufacture as indicated in the following diagram:



Schematic Diagram

The Manufacture of Portland Cement



Conditions Affecting the Properties of Cement:- Read Articles 350 to 354 inclusive. The properties mentioned in these articles will be described in detail in Chapter XII begining on page 371 in the text.

Soundness is the most important property of cement. Unsound cement cracks and disintegrates after it has set. It is thought that the principal element causing unsoundness is free lime. Thorough seasoning, fine grinding of the raw materials and the clinker, and the use of the minimum amount of gypsum tend to prevent unsoundness.

Fineness of grinding is the principal factor affecting the tensile strength of cement mortar. The tensile strength of sand mortars is improved, but that of neat cement mortar is decreased by fine grinding.

The time of set is decreased by fine grinding of the cement. Finely ground cements sometimes develop a flash set which makes them unfit for use in engineering structures. The degree of seasoning, the temperature of the air and the mixing water all affect the time of set.

The fineness of cement is influenced by the hardness of the klinker and the efficiency of the grinding machinery used. There is no relation between the strength of concrete and the fineness of cement if different cements are considered.

Long seasoning is the chief cause of a low specific gravity of cement.

1. Define portland cement.

2. Explain the derivation of the term portland in the name portland cement.

3. Outline the process of manufacture of portland cement.

4. What are the names of the principal constituents of portland cement?

5. State the colloidal theory of setting and hardening of cement as advanced by Michaelis.

6. What is the temperature at which cement is calcined?

7. What is meant by incipient fusion?

8. How does fine grinding effect the strength of neat cement mortar?

9. What is the principal cause of unsoundness in cement?

10. Define unsoundness.

UNIVERSITY OF CALIFORNIA EXTENSION DIVISION

Correspondence Courses

Materials of Engineering Construction

Assignment 10.

Civil Engr-8.A1 Professor C.T. Wiskocil

PORTLAND CEMENT (continued) and NATURAL CEMENT

Tensile and compressive strength of cement:- Read Articles 355 and 356. As has already been mentioned, neat cement is rarely used in engineering construction. Recently it has been used to make joints in laying bell-and-spigot cast iron pipe. The cement is mixed with just enough water to hydrate it so that when ready for use it is not a paste but is merely moist. In this condition it can be rammed into the joint where it hardens without shrinkage cracks. These joints have been very successful.

Most of the tests on neat cement were made during the development and standardization of this important structural material. Those reported in Bulletin 333 of the United States Geological Survey (mentioned in Article 356) were made in the period from 1905 to 1907. They were published in 1908. Since that time it has been found that the strength of neat cement is no criterion of the strength of mortar or concrete made from it. Furthermore, tensile strength tests of a given cement have been found to be decidedly influenced by the methods of mixing and molding and other variables that may be grouped into what is called the personal equation. Standard specifications once included the test of neat cement, but it should be noted that at the present time only a 1 to 3 standard sand mortar is tested (see page 372 of the text).

The data given in Figure 13 on page 331 do not check those given in Figure 16 on page 335. Remember that in addition to the personal equation, conditions of storage, temperature of mixing water, form of briquette, and amount of mixing water used all effect the strength of the cement; moreover, different brands have individual qualities. The principal difference between the sets of data mentioned is that those in Figure 16 do not show the decided decrease in strength at the age of one year. Since the tensile strength of neat cement is not important it is sufficient to remember that the strength increases with age to a maximum of about 1,000 lb. per sq. in.

The compressive strength of neat cement also varies with age, the size and shape of the test-specimen, and the amount of mixing water used. The consistency of the freshly made cement paste varies considerably with the amount of water used; yet, in spite of the fact that this factor has a great influence on the ultimate strength of the hardened mortar, it was seldom recorded in early experiments, such as those used in preparing Figure 14 in the text. The data in Figure 14 show that the compressive strength of neat cement one year old varies from about 11,000 to 13,000 lb. per sq. in. Some tests reported by A.C. Alvarez in THE COMPRESSIVE STRENGTHS OF PORTLAND CEMENT MORTARS OF VARIOUS PROPORTIONS, University of California Publications in Engineering (1915), give the compressive strength of neat cement mortar cubes, 49 days old, as 10,000 lb. per. sq. in. The cement paste was of normal consistency, 22% water

being used. Increasing the amount of mixing water would decrease the ultimate strength. The relation would probably be similar to that shown in Figure 1 on page 816 in the text. The effect of the variable amount of mixing water and another variable, the molding pressure, is clearly shown in an article, PRESSING OUT MIXING WATER ADDS TO CEMENT MORTAR STRENGTH by C.T. Wiskocil, Engineering-News Record, 83, 130 (July 17, 1919). The following facts are taken from that article: "Neat cement mortar made with 25% water had a compressive strength of 6,800 lb. per sq. in. at 7 days. Increasing the amount of water to 37% reduced the 7-day strength to 2,500 lb. per sq. in. The paste used in making the latter specimens ~~were~~ was molded under a pressure of about 30,000 lb. per sq. in., allowing the expressed water to escape, ~~produced~~ These pressure specimens ~~whose~~ had a 7-day strength ~~was~~ of 17,000 lb. per sq. in."

Since the strength of neat cement is not important, take 10,000 lb. per sq. in. as the average compressive strength. It is easily remembered with the 1,000 lb. per sq. in. for the average tensile strength.

Expansion and contraction due to changes in moisture content:-

Read Article 357. The important fact is that dry mortar as well as concrete (see Article 522 on page 480 in the text) will expand when it becomes wet and contract again upon drying. Frequently changes in moisture content are as important as temperature changes in producing variations in linear and volumetric dimensions of mortar and concrete.

Effect of remixing on the strength of cement:- Read Article 358. The practice of using cement that has set is seldom allowed in engineering construction. Remixing is the use of set cement while retempering is the addition of water to set cement; but since neither practice is in general use the subject is not important. Remixed mortar is frequently used in laying floor and wall tile because of the impression among the artisans that this procedure increases the cementing qualities of the mortar. The data in Figure 21 show that the compressive strength of neat cement mortar is not materially affected by remixing even several hours after it has been prepared.

The central mixing plant, which necessitates some long hauls of wet concrete, is frequently used in road construction, particularly on large contracts. Recent tests by the Bureau of Public Roads show that the compressive strength of concrete will not be affected so long as it remains workable. Test specimens made from wet concrete which had been hauled in trucks for periods up to three hours showed no appreciable decrease in compressive strength. The concrete, however, became too dry for hand finishing 45 minutes after it had been prepared. These remarks are inserted at this point because the subject is not discussed under CONCRETE in the text.

Effects of high and low temperature on cement:- Read Articles 359 and 360. The setting and hardening of cement paste is retarded and may be entirely stopped by decrease in temperature. These effects are not appreciable until the temperature falls below

40 degrees Fahrenheit. Alternate freezing and thawing of cement before it sets is particularly harmful.

High temperatures produce marked reductions in the strength of cement mortar. Remember that cement begins to fuse at approximately 2,800 degrees Fahrenheit.

Temperature of cement during period of set:- The effect of alkali on the durability of cement concrete is being intensively studied at the present time. As yet no conclusions are available. There are numerous examples of failure of cement subjected to the influence of alkali but the history of the preparation of the concrete, which is thought to have considerable effect on its durability, is not always available.

Sugar and animal and vegetable oils disintegrate cement mortar and concrete.

Effect of storage on cement:- This subject is not satisfactorily discussed in the text (see page 373) but it is one that can be taken up at this point. The question is important because a shortage of fresh cement on a job will frequently necessitate the use of cement that has been stored from six months to a year or produce an enforced delay until a new shipment can be secured. The storage of cement is of interest to the manufacturer and dealer as well as the user because it is becoming the practice to deliver concrete materials on the job prior to the opening of the construction season. The principal study of this question has been made at the Structural Materials Research Laboratory, Lewis Institute,

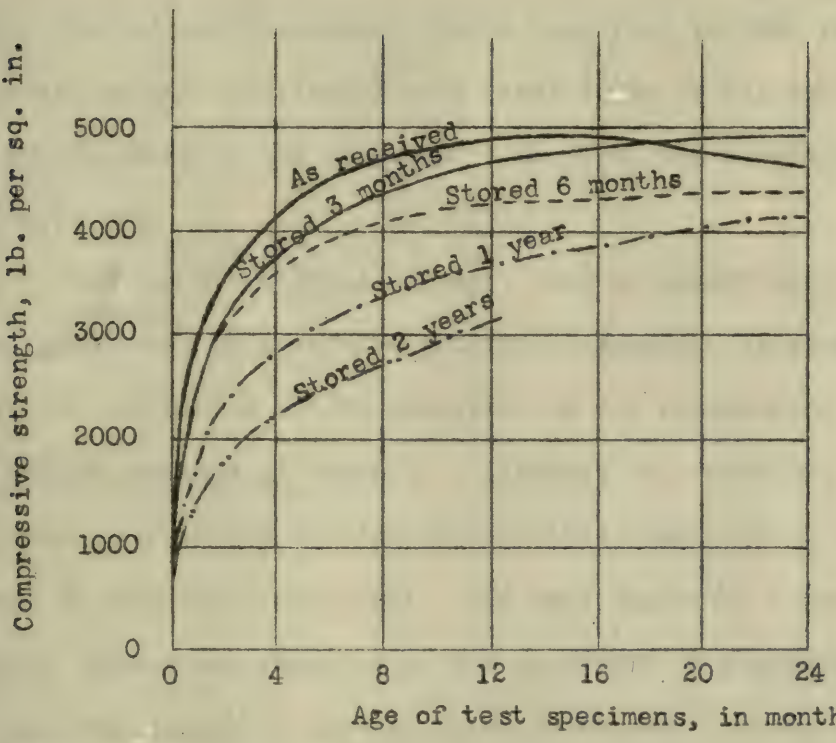
Chicago, and reported in Bulletin 6, EFFECT OF STORAGE OF CEMENT, by D.A. Abrams.

The cement was stored in cloth and paper sacks under three different conditions; namely, indoors with uniform temperature and low humidity, indoors at lower temperature and higher humidity (average basement conditions), and under average shed conditions, which afford protection from direct contact with rain and snow but allow free circulation of outside air with variable temperature and humidity.

The principal conclusions are the following: There is no marked difference in the quality of the cement stored in paper and cloth sacks for periods up to 1 1/2 years of storage. The exact condition of storage is not of great importance so long as the cement is protected from direct contact with moisture.

The deterioration of stored cement is probably due to the absorption of moisture from the air, which causes a partial hydration of the cement. The principal effect on the mortar and concrete making qualities are the decrease of early strength and the prolonging of the time of setting.

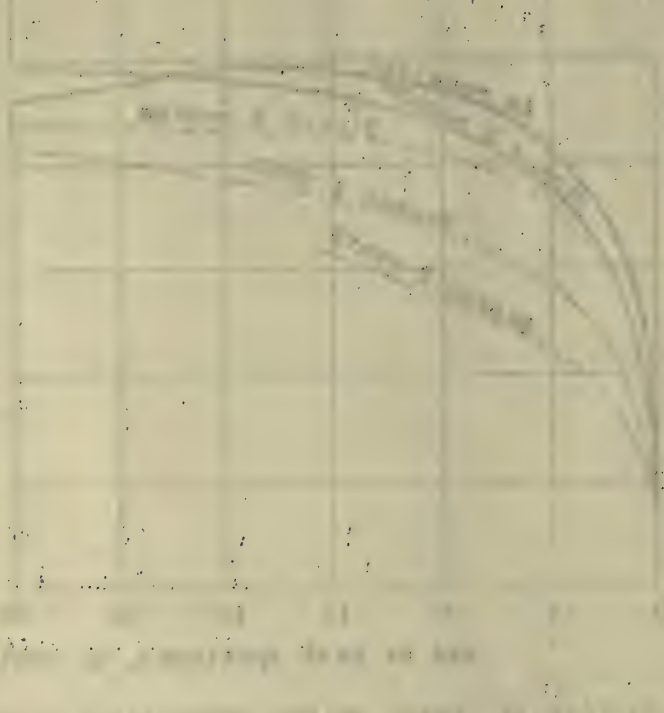
The effect of storage is clearly shown in the accompanying diagram.



The Effect of Storage of Cement on the compressive strength of 1-5 concrete tested at different ages.

The compressive strength of concrete and mortar showed a decrease in strength with storage of cement for all samples, for all conditions and periods of storage and at all test ages. The decrease was greatest for the samples stored in the shed and nearly as great under basement storage.

The age of the concrete has a large influence on the results obtained. Taking the poorest condition of storage, that under the shed, the specimens tested at the age of 7 days, made from cements and all periods of storage, was 64% of the strength of the specimens made with cement when received from the warehouse; at 28 days, 71%; at 6 months, 78%; at 1 year, 82% and at 2 years 85%. Similar results were obtained from specimens under



other conditions of storage. These data tend to show that the strength of concrete, say 3 or 4 years after it has been poured, is not affected by the length of time (age) the cement was stored prior to use.

The use of reclaimed cement, that is cement that is obtained from used sacks of pneumatic methods or shaking, is questionable practice and should not be permitted on any engineering structure.

Effect of fineness of cement:- Fineness is a distinct property of cement and should be discussed at this time. It is briefly noted on page 322 in the text. The most important tests were made by D.A. Abrams and reported by him in EFFECT OF FINENESS OF CEMENT in the Proceedings of the American Society for Testing Materials, Vol XIX, part II, 1919. The following are his principal conclusions:

There is no necessary relation between the strength of concrete and the fineness of the cement, if different cements are considered.

In general, the strength of concrete increases with the fineness of a given lot of cement.

Fine grinding of cement is more effective in increasing the strength of lean mixtures than rich ones.

The principal result of finer grinding of cement is to hasten the early hardening (strength) of the concrete.

Fine grinding of cement reduces its time of set.

Ordinary concrete mixtures show an increase in strength of about 1.5% for 1% reduction in the residue of the cement on the No.

200 sieve. (Remember that the fineness is measured by the residue on a No. 200 sieve.)

It has been found by other investigators that the principal cause for rejection of finely ground cement is the development of a flash set after delivery; the mill tests showing the cement to be normal at the time of shipment.

Natural cement:- Read Articles 365 to 369 inclusive on natural cement. When clay-bearing limestone is heated to about 2000 degrees Fahrenheit, it gives off carbon dioxide and forms a clinker, which when finely ground is known as natural cement. The clinker will not air slake but when mixed with water the resulting paste will harden in air or under water just as portland cement does. Natural cement is not as uniform as portland cement and it has less strength. In spite of its cheapness ~~it is~~ very little is used. It has been used for mortar for masonry and for concrete where strength was not a prime requisite.

Miscellaneous cements:- Read Articles 370 to 378 inclusive. White portland cement is probably the most important of the varieties mentioned. It is impossible to get the proper shades of color in stucco made with colored aggregate when using the ordinary grey portland cement; white portland cement is used almost exclusively for this purpose. In the construction of light colored masonry it is necessary to have a mortar that will not stain the stone. White portland is much more satisfactory than a natural cement (which is also stainless) for this purpose.

Puzzolana cement:- Puzzolana is the name used in Europe to designate the cements made from volcanic material. These were first used as a cementing material at Pozzuoli, Italy. Puzzolan (pronounced pŏt'-swō-lăn') cements were widely used in the days of the Roman Empire. A few of the structures made at that time are still in a fair state of preservation. This class of cements include all hydraulic cementing materials which are made by the incorporation of natural or artificial puzzolans with hydrated lime without subsequent calcination. The only natural puzzolan materials of importance are puzzuolana, trass, and tuff or tufa. Blast furnace slag is an artificial puzzolan material. Do not confuse the so-called slag cement with the true portland cement made with blast furnace slag. The tufa cement used in the construction of the Los Angeles aqueduct was neither a true portland nor a true puzzolan cement. It was a blended cement as described in Article 372.

These blended, improved, or puzzolan cements are never brought into competition with portland cement where great strength is required.

Alumina cements:- Alumina cements are not discussed in the text probably because they have never been made on a commercial scale in this country. In France, where they were produced first, they are only now coming into general use.

Alumina cements differ from portland cements in chemical composition and the rate of hardening. Both mortars and concretes

develop greater strength within 48 hours (and in most instances within 24 hours) than corresponding mixtures made with portland cement develop in 28 days. Furthermore, alumina cements have great resistance to the action of sea water and alkali-bearing waters.

Investigations on these cements were begun about 1902 by H.S. Spackman and E. W. Lazell in the United States. In France, J. Bied began his studies on this material in 1908. Recently P. H. Bates of the United States Bureau of Standards has reported on his study of alumina cements. In 1912 the firm of J. and A. Pavin Lafarge marketed alumina cement under the name of CEMENT FONDU. It was manufactured for military use, only during the war, but in 1919 its commercial use was resumed.

The approximate composition of alumina cement is 50% lime, 40% alumina and 10% silica and impurities. It is sometimes referred to as a mono-calcic aluminate. It is low in lime and silica, and high in alumina as compared with normal portland cement. In France it is made in small blast furnaces which are charged with coke, limestone and bauxite. The fused slag or clinker is cooled and ground. If the bauxite is pure the cement is white in color but the commercial cements are darker than portlands because of the impurities in the raw materials. Since actual fusion is not necessary this cement could be made with the same machinery used in the manufacture of portland cement. The cost of manufacture of the cements would be about the same but the actual cost of alumina cement is dependent upon the cost of bauxite which at present would

bring it over that of ordinary portland cement.

Alumina cements are slow setting and are gaged like the ordinary portland cement. Reports on the French cements give, for a 1:1:3 gravel concrete, compressive strengths of

7,500 lb. per sq. in. at 3 days
8,500 lb. per sq. in. at 28 days
9,000 lb. per sq. in. at 3 months

Other reports state that a 1 to 3 sand mortar developed 75% of its own 28-day strength in 24 hours. During the war heavy guns were moved on alumina-cement-concrete foundations 24 hours after they had been poured.

1. How does a change in moisture content of hardened cement mortar effect its volume?

2. Give the approximate tensile and compressive strengths of neat cement mortar.

3. Name the various factors that affect the strength of cement mortars.

4. Does the long haul of wet concrete, made necessary by the use of central mixing plants, affect the strength of the hardened concrete?

5. What is the principal precaution to be taken when storing cement?

6. Would you allow the use of cement that had been stored on the job - say for 18 months?

7. Under what conditions would you allow the use of so-called reclaimed cement?

8. How does the fineness of the cement affect the time of set and what is the importance of time of set?

9. What is the relation between the strength of concrete and the fineness of the cement used?

10. Differentiate between slag cement and portland cement made from blast furnace slag.

11. Will natural cement set under water?

UNIVERSITY OF CALIFORNIA EXTENSION DIVISION

Correspondence Courses

Materials of Engineering Construction

Assignment 11.

Civil Engr-8.A. Professor C.T. Wiskocil

LIME

Introduction:- Lime, as used in the preparation of mortar, was one of the building materials used by the early Greeks and Romans. Probably the earliest known use of lime-mortar was in the construction of the Egyptian pyramids. During the recent war the manufacture of lime was declared to be an essential industry, not because of its use in building construction - although large quantities were used in the construction of buildings by the United States Housing Corporation - but on account of its importance as a chemical reagent in the manufacture of guncotton, leather and other essential products.

Definition and classification:- Lime is the product obtained by heating limestone so as to drive off the carbon dioxide. It is, therefore, a calcium oxide. Study Article 379; it contains a more detailed definition and a partial classification of lime. There are two general grades of lime; selected and run-of-kiln, both of which are described in the article noted. Lime is frequently sold as lump lime, in which the size of the individual pieces is left as they come from the kiln, and powdered lime, which is broken up so that it will all pass a 1/4 inch screen. The classification adopted by the American Society for Testing Materials is referred

to in Article 379; it is as follows: high calcium lime, not less than 90% calcium oxide; calcium lime, not less than 85 or more than 90% calcium oxide; magnesian lime, not less than 10 nor more than 25% magnesium oxide; and high magnesian lime, not less than 25% magnesium oxide. If these limes contain less than 5% of silica, alumina, and iron oxide, which are known as impurities, they are called rich or fat limes. Limes containing more than 5% of these impurities (noted above) are known as poor or lean limes. Sometimes lime is classified according to the purpose for which it is best fitted, as agricultural, building, finishing, or chemical lime.

Manufacture:- Study Article 380 and read Article 381. While limestone has been described before, review some of the important facts about it since it is the raw material from which lime is made. Since limestone is of sedimentary origin it is never found pure. It is essentially calcium carbonate with impurities of magnesia, iron, alumina, and silica. Very pure cyrstallized limestone is called calcite. When the amount of magnesia increases it is called magnesian limestone until the ratio of calcium to magnesium carbonate becomes 100 to 84; it is then called dolomite. When magnesia remains low but impurities increase, the rock may be an argillaceous limestone, natural cement rock, or calcareous shale.

There are three principal types of kilns for burning lime; the pot kiln, the patent kiln and the rotary kiln. The mixed-feed type described in the text is the pot kiln. The separate-feed type

is the patent kiln, and is the best type.

As indicated in Article 379 the reaction produced in the heating of limestone is essentially

$$CaCO_3 + \text{heat} \longrightarrow CaO + CO_2$$

The carbon dioxide is driven off as a gas which leaves the lime as a mixture of oxides. The amount of heat required depends upon the chemical composition of the stone. Under ordinary conditions calcium carbonate breaks up at 898°C (1648° F.) When the temperature reaches about 2190°F, the calcium oxide and the impurities in the stone combine to form compounds that produce partial vitrification and retard the slaking of the lime. The required amount of heat may be supplied quickly at a high temperature or over a longer period at a lower temperature. Since the activity of the impurities becomes noticeable below 2100°F., better quality is secured at lower temperatures of burning. Wood-burned lime, because of the lower temperature of burning, usually commands a higher price than coal-burned lime. The introduction of steam into the kiln during the burning process tends to increase the quality of the lime by decreasing the temperature of decomposition from 1648°F to about 1450°F.

Slaking or hydration of lime:- Study Article 382. Quicklime is prepared for use in building construction by slaking which is the addition of water to form a paste. Slaking is a process of hydration, in which the calcium oxide combines with water to form the hydroxide.

$$CaO + H_2O \longrightarrow Ca(OH)_2$$

Slaking is usually done in a shallow watertight box. The water is poured over the lime. High calcium lime must be stirred continuously to prevent the heat generated from burning the lime. The water absorbs the excess heat. Too much water lowers the temperature and retards the slaking, impairing the plasticity of the product. The addition of too much water is known as drowning. A high-calcium lime is subject to burning while the slaking of a high-magnesian lime must be watched to prevent drowning. A skilled operator is required to slake quicklime properly. Both underburned and overburned lime will slake more slowly than that which is properly burned. The rate of hydration (slaking) indicates the burning temperature. Slaked lime, which is a thick paste, is sometimes called lime-putty. It will keep indefinitely if it prevented from drying out. It is stored in casks or in the boxes in which it is made. It will not harden under water.

Setting and hardening:- The setting is caused by the evaporation of excess water from the lime paste. Hardening is a chemical action involving the replacement of the water in the hydroxide by carbon dioxide, with the result that the lime paste reverts to the calcium carbonate. Hardening is accelerated by increasing the amount of carbon dioxide in the air and by the use of moist air. The first condition is produced by the use of salamanders and the second by the frequent wetting of mortar. These methods are used in hardening interior plastering.

Properties of lime:- Study Article 385. In general, lime is a white substance which will slake when water is added to it. During the slaking process the water enters into chemical combination with the lime with a resulting generation of heat and increase in volume. When exposed to air, slaked lime will set and harden. The carbon dioxide from the air combines with the lime and forms the carbonate. Setting is always accompanied by a decrease in volume.

Lime when exposed to air will air-slake as described in Article 382. This term air-slaked lime is rather confusing, because the substance is practically identical with finely ground limestone and therefore has no value as lime for structural purposes.

The strength of lime mortar depends principally upon the method by which it is prepared and the kind of sand used. Mortar made with dolomitic lime is generally stronger than that made with high-calcium lime. This may be due to the fact that the greater shrinkage in high-calcium lime mortars may tend to weaken the bond. Moreover, magnesian mortars are made up with less water so that they contain more actual binding material; and again, since high-calcium limes will carry more sand they are frequently overloaded; that is, the proportion of lime paste to sand is relatively large and hence the resulting mortar is weak.

Lime mortar is never used where strength is required. The choice between limes should be made not on the basis of strength but rather on relative cost and previous experience.

Mortar joints in masonry are seldom over 1/2 inch thick. The actual resistance to compressive loads is therefore greater than indicated in the tables such as the one given on page 364.

Commercial forms:- Lime is put on the market in two forms, lump and ground. Lump lime is shipped in bulk and in wooden barrels of 180 or 280 lb. net capacity. Ground lime is screened through a 60 mesh sieve and shipped in air-tight casks.

Hydrated lime:- Study Article 383. Ordinary quicklime is treated at the mills, with only enough water to slake it completely. Hydrated lime is a fine powder consisting of calcium hydrate and magnesium oxide. Mechanical hydrators are used and the product is under strict control. The tensile and compressive strengths of hydrated lime mortars are higher than those of the corresponding quicklime mortars. Hydrated lime mortars, besides having greater strength, set more quickly and shrink less than ordinary quicklime mortars, but the latter excel in plasticity, sand-carrying capacity, and yield.

The consumer must pay freight on a considerable amount of water when he buys hydrated lime, but in its use the danger of burning or drowning and the time and labor required in the slaking of quicklime are eliminated.

The principal use of hydrated lime as a structural material is in portland cement mortars and concretes.

Testing of limes:- Read Article 384.

Uses of lime:- Read Article 386. Besides the uses mentioned in this article lime is used for the manufacture of sand-lime brick,

and of glass, paints and paper. It is also used as a fertilizer and in the tanning of leather.

Hydraulic lime and grappier cement:- Read Articles 387 and 388. Hydraulic lime was used for structural purposes before the superior natural and portland cements were introduced. Its use at the present time is limited.

The raw material is a siliceous or argillaceous limestone. The ideal stone is one that has sufficient free lime remaining after calcination to disintegrate the clinker by its disruptive action when slaked. During calcination the silica combines with the lime to form lime silicate which gives the product its hydraulic properties. The slaking of hydraulic lime, as in the case of hydrated lime, is done by the producer. The lumps that are not disintegrated during the slaking process do not contain a sufficient amount of lime or they are under-burned. These lumps have been called grappiers. When they contain sufficient lime silicate they are finely ground and marketed as grappier cement. Lafarge cement, noted in Article 388, is a grappier cement.

The properties of hydraulic lime are very low in value, when compared to those of portland cement.

GYPSUM

Introduction:- Read Article 389. Wall plasters and plaster of Paris, as noted in this article, are made of gypsum. It is also used in the manufacture of precast structural products and structural members cast in place. Gypsum is added to portland cement to retard its set, and raw gypsum, which is known as land-plaster,

is used as a fertilizer.

Occurrence:- Read Article 390. Gypsum is a common mineral; its most distinguishing characteristic is its extreme softness. The pure material consists of approximately 32.6% lime, 46.5% SO_3 and 20.9% water. It is a neutral substance; that is, it is neither acid nor basic.

Calcined gypsum:- Read Article 392. Calcined gypsum is known by many names, some of which are derived from the purpose for which it is used, as dental plaster, molding plaster, casting plaster and potter's plaster. These materials are all calcined gypsum and differ only in the time of set, which has been regulated. The most common name for calcined gypsum is plaster of Paris.

Calcined gypsum is produced by heating finely ground raw gypsum. The product is made in kettles which hold from 2 to 20 tons. During the heating process the gypsum is continuously stirred by a power-driven paddle. The water held in chemical combination is driven off as steam which fluffs up the whole mass and makes it appear to boil. It settles down to its normal volume when the boiling action ceases; this usually takes about an hour for a kettle full of material. The exact time depends upon the charge and the temperature. The product is calcined gypsum but to the operator it is known as first-settle stucco. It is partially dehydrated gypsum, with chemical formula usually written $CaSO_4 \cdot 1/2 H_2O$. Calcined gypsum, when mixed with water, sets and hardens rapidly to form a material identical with the original gypsum

rock. The setting of normal calcined gypsum occurs in from 5 to 10 minutes. When used for dental purposes the time of set is accelerated but when used as a wall plaster the time of set is retarded. Some wall plasters are regulated so as to set in about 20 minutes while in others the set is retarded to about six hours.

Set gypsum, when the normal calcined gypsum is used, has an approximate compressive strength of 1,500 lb. per sq. in. and a tensile strength of 400 lb. per sq. in. Since moisture in the specimen decreases its strength, the maximum value can be developed only when the material is dry. The amount of mixing water has a decided effect on the strength of set gypsum. For maximum strength the least possible amount of mixing water should be used.

Gypsum wall plaster:- Read Article 393. It has been estimated that three-quarters of the gypsum mined is made into wall plaster. Calcined gypsum is the simplest wall plaster. It is not used pure but is added to lime paste.

Calcined gypsum is not plastic and therefore is difficult to spread with a trowel. It has become the practice to add about fifteen percent of clay or hydrated lime to it at the mill. A retarder is added to the material so that it will set in from one to six hours. This product is known as hard-wall plaster on the eastern market, but in the west, the same material is called cement plaster.

The principal disadvantage of calcined gypsum when used pure is its lack of plasticity. By proper methods of manufacture, which

are explained in an article, PLASTIC GYPSUM MADE POSSIBLE BY A NEW METHOD, by W.E. Emley, Engineering News-Record 86, 1023, June 16, 1921, it can be made as plastic as lime. Fine grinding of calcined gypsum liberates the water of crystallization just as heating does. If the escape of the water is prevented, so that the finely ground gypsum contains the water of crystallization, it produces not only a more plastic and slower setting material but also a stronger one. If the water of crystallization is allowed to escape during the grinding process the product will be the soluble anhydrite which rapidly reabsorbs water from the air and reverts to the calcined gypsum. There is no advantage in fine grinding under such conditions. The new plastic-gypsum is very stable; it has been exposed to air for four months without apparent detriment to its plasticity.

Second-settle calcined gypsum:- If calcined gypsum is properly heated it will appear to boil and subside just as the raw gypsum did when it was heated. During the second boiling all the water held in chemical combination is driven off so that $CaSO_4$ remains; this is anhydrous calcium sulphate. To distinguish between this product and the natural anhydrite which has the same formula but very different physical properties, the former is called soluble anhydrite. The mineral anhydrite is quite inactive. It is weeks before it combines with water to form set gypsum. The soluble anhydrite sets more rapidly than the calcined gypsum and makes a harder and stronger set gypsum. The soluble anhydrite is not stable - it readily absorbs water from the air to form the

calcined gypsum; but because of its greater strength it is used at the mill to make precast products. The material cannot be shipped or stored.

Hard finish plasters:- Read Article 394. Calcined gypsum is changed to the soluble anhydrite at about 500 degrees Fahrenheit. The latter material is converted into the natural or mineral anhydrite by prolonged heating or higher temperatures. In spite of its slow set, the natural anhydrite is used in Europe as a floor surface.

Keene's cement is described in the text on page 369. It sets more slowly than calcined gypsum and makes a harder surface.

Gypsum building products:- Read Article 395. One variety of gypsum tile, which is generally used for partitions, is made at the mill with calcined gypsum to which about 5% of wood fiber has been added. This variety is made cellular like the clay partition blocks shown on page 293. The usual dimensions are 12 by 30 inches with thicknesses varying from 2 to 8 inches.

Roofing tile must be stronger than partition tile. They are, therefore, made of second-settle calcined gypsum and are frequently reinforced with steel rods and wire-mesh. Standard roof coverings are used to protect gypsum tile from the weather. Kiln-dried gypsum products, like roofing tile, gain their full strength within a few hours.

Gypsum plaster board is made in laminations - a thin layer of calcined gypsum between layers of paper. It is used as sheet-lath as a base for plaster. The gypsum usually contains a wood-fiber to decrease its brittleness. Gypsum wall board is

similar to the plaster board. In the case of the latter, however, plaster is applied to the surface while the wall board has a smooth surface and is not plastered, but forms the finished wall. Sheetrock is the trade name for a gypsum wall-board now being widely advertised.

Structural members such as roofs can be poured into place just as in cement-concrete construction. On page 4 of the advertising section of the March 23, 1922 issue of the Engineering News-Record, is an illustration in which the roof of the National Tube Company's plant at Lorain, Ohio, is being poured with gypsum. Structural gypsum gains strength rapidly; the forms are taken off the day after the gypsum has been poured. The compressive strength is affected by several variable factors, the principal ones being the amount of mixing water used and the amount of aggregate - sand or wood-fiber. Prolonged moisture reduces the strength of structural gypsum. An average value of the compressive strength is 1,500 lb. per sq. in. It weighs about 80 lb. per cu. ft. and has a modulus of elasticity of about 1,000,000 lb. per sq. in.

Magnesia cement:- This material is not discussed in the text. It is made by mixing magnesium oxide with a solution of magnesium chloride. Various aggregates such as, sand, sawdust and asbestos, are added to the cement. It is sometimes called Sorel cement, after its inventor, Stanislaus Sorel, and also magnesium oxychloride cement. It is used principally as an interior wall finish and as flooring. In the East it is now being used as an exterior wall surface.

The magnesium oxide is prepared by calcining and grinding magnesite ($MgCO_3$). There are large deposits of magnesite on the Pacific Coast. The more important deposits which are being worked are in Greece, Italy, and Austria.

The methods of manufacture and the properties of magnesia cements are being studied by the U.S. Bureau of Mines and the Dow Chemical Company, who operate a well equipped magnesium-oxychloride research laboratory.

The following notes were taken from reports by the Dow Chemical Company.

The standard stucco mix is 1 part calcined magnesite to 2 parts Silex (powdered silica) to 5 parts graded silica sand mixed with 22 degree Baume magnesium chloride. The strength of this material varies (from various test results) from 200 to 1000 lb. per sq. in. at 30 days. When placed on the wall its average tensile strength is about 500 lb. per sq. in. Its compressive strength is about 5 1/2 times its tensile strength. Its modulus of elasticity is approximately 3,000,000 lb. per sq. in.

Standard flooring mix is 5 parts calcined magnesite, 3 parts Silex, 1 part ground talc, 1 part fiber (wood or asbestos) and one part color pigment, all mixed with 22° Baume magnesium chloride. For heavy duty the following mixture is used: 12 1/2% calcined magnesite, 35% Silex, 62 1/2% pure silica sand. This is also mixed with 22 degree Baume magnesium chloride. Magnesite makes a sanitary, resilient floor which has a good appearance and excellent

wearing qualities. It is free from the splintering action of wood floors and is not subject to dusting or sanding. By actual test it was found to be more durable than linoleum.

Most of the early literature on the subject states that oxychloride cements are disintegrated by continuous wetting or immersion in water. At the present time it is believed that the degree of burning affects the water resisting properties. Since oxychloride cements are used for exterior stucco it is evident that when properly designed and applied they are water resistant. Commercial magnesium cements can be secured which make a stucco that is practically water resistant.

QUESTIONS

1. What is slaked lime?
2. What precautions must be taken in slaking lime?
3. Can lime mortar be used under water?
4. What is dolomitic lime?
5. How is hydrated lime made?
6. Outline the manufacture of calcined gypsum.
7. What are the general uses of gypsum as a structural material?
8. What factors affect the strength of gypsum?
9. How does plastic-gypsum differ from ordinary calcined gypsum?
10. What is magnesium-oxychloride cement? What is it used for?

UNIVERSITY OF CALIFORNIA EXTENSION DIVISION

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Materials of Engineering Construction

Assignment 12.

Civil Engr-8A Professor C.T. Wiskocil

TESTING OF HYDRAULIC CEMENTS

Necessity for testing cement:- Read carefully that part of Article 396 which is given on page 371, and then Article 443. The third paragraph on page 371 is very important - study it. The physical tests are the most important and are made for the purpose of comparing the given cement with a standard which has been adopted after long experience. The results of laboratory tests do not represent the properties of the material under working conditions but they are of relative value when compared with test results of cements that have been found satisfactory in practice.

Standard Specifications for portland cement:- Read the remainder of Article 396. Study the parts marked II and V, because they are important. Be able to name the various tests and give the standard requirements. These specifications are used throughout the United States. The United States Government specifications are substantially the same.

STANDARD TESTS

Sampling:- Read Articles 397 to 401 inclusive. The important thing to be remembered in selecting a sample of cement is that it should be fairly representative. This is well emphasized in the text, together with the importance of proper storage and mixing.

in the quartering process described in Article 401, it is the usual practice to ~~disregard~~ reject opposite quarters of the pile and combine the remaining quarters which are again mixed and divided into quarters. The process is repeated until the amount remaining gives the size of the sample desired.

Chemical analysis:- Read Articles 402 and 407. Since the chemical tests are relatively unimportant, omit Article 403 to 406 inclusive.

Specific Gravity:- Read Articles 408 and 448. This test is not very significant. For that reason, as indicated in the specifications on page 372, it is made only when specifically called for. Adulterants such as, Slag, limestone, and natural cement could be present in quite appreciable amounts before the specific gravity would be noticably affected. The specific gravity test does, however, indicate the degree of seasoning. Cement clinker and ground cement both absorb water and carbon dioxide from the air, causing the specific gravity to decrease. The loss due to seasoning is regained upon ignition of the sample.

Low specific gravity may be the result of adulteration. It is also indicative of the degree of seasoning. Since seasoning is desirable in portland cements a value below 3.10 for the specific gravity should not be cause for rejection without some definite reason based on the history of the cement in question.

Fineness:- Read Articles 409 to 412 inclusive, and Article 447. The paragraphs marked 34, 35, and 36, in Article 409, are the most

important. The standard method of hand sieving is given preference over mechanical methods. Since the sand carrying capacity and compressive strength of mortar and concrete are increased by fine grinding it is desirable for the manufacturer to obtain the maximum degree of fineness compatible with reasonable manufacturing costs. Fine grinding decreases the time of set.

Fine cements will leave a residue of about 2% on a No. 200 sieve while those of average fineness leave from 10 to 15%.

Article 412 is relatively unimportant. The air analyser developed by the United States Bureau of Standards, mentioned on page 381, has proved to be very satisfactory in separating into smaller sizes cement which passes the No. 200 sieve.

Mixing of cement paste and normal consistency:- Read Articles 413 to 418 inclusive. The making of cement paste and mortar is of importance in the laboratory in which test specimens are prepared. The cement paste is used in the determination of soundness and the time of set. Cement mortar is made into briquettes for the tension test. In order to obtain results comparable to those given in the text the cement paste and mortar should be made in strict accordance with the directions in the text. In a general course in MATERIALS these directions are relatively unimportant.

The plasticity or consistency, as it is called in the text, affects the strength and also the time of set. It is necessary, therefore, to have cements tested under the same conditions as those under which the standard tests were made. This is accomplished by having the cement paste of a given plasticity as

determined in a specified manner with the Vicat apparatus illustrated on page 383. This determination is of importance only in the laboratory. A cement paste is of normal consistency when the rod of the Vicat apparatus, which weighs 300 g. and is 1 cm. in diameter, sinks 10 cms. into the paste in 1/2 minute after being released. This method is very satisfactory - but only for neat mixtures. The amount of water to be used for sand mixtures, in the standard tension tests is given in the table on the top of page 384. Articles 417 and 418 are not important.

Soundness:- Read Articles 419 to 424 inclusive and Article 444. Soundness is the most essential property of cement. The ability of a cement to develop a high degree of strength is of no value if it is not able to withstand the disintegrating effects of the atmosphere when it is finally placed in the structure. While the conditions in this test are more severe than those to which the cement will be subjected when it is put in use, the results are, nevertheless, quite satisfactory in indicating the durability of a given cement. The illustrations on page 386 show parts that have failed to pass the soundness test. Articles 421, 422, and 423 are not important.

Time of setting:- Read Articles 425 to 427 inclusve and Article 446. The rapidity with which a cement sets is a criterion of its adaptibility under given conditions of use. In some types of construction it might be desirable to have a cement which would set quickly. In other circumstances, where it is impossible to place the concrete without delay, it is necessary to have a slower

setting cement. The influence of the temperature and the amount of mixing water used are explained on pages 327 and 328 in the text. The tables are given in a previous assignment but it is desirable to review the general affect of these variables at this time. Paragraphs marked 48 and 50 in Article 425 are the most important.

Tension test:- Read Articles 428 to 439 inclusive, and Article 445. The standard tension test is made on briquettes of sand mortar. The proportions of the mortar are, one part cement to three parts standard sand, mixed with the amount of water determined by the normal consistency test, according to the table on page 384. A special sand, described in the paragraph marked 52 on page 391, is used.

Study Articles 429 and 431. The latter article explains that the stress across a briquette under test is not uniform. This non-uniformity of stress in a test specimen is an undesirable feature in a tension test. Since the modulus of elasticity of mortar varies with age, the tension tests at various ages do not give a true indication of the variation in the average tensile strength of the material. This is not important in the standard tests here described but it is important in research problems. In such work the compression test on cylindrical specimens is more generally used.

Articles 432, 433 and 434 are not important.

Storage of test specimens:- Test specimens are stored in a moist closet, as described in Article 441, for 24 Hours. After

that they are removed from the molds and immersed in water. As stated in Article 440, it is important that the temperature of the air in the moist closet and the temperature of the water, in which test specimens are stored, should be as nearly 70 degrees Fahrenheit as possible.

Miscellaneous methods of testing cements:- Read Articles 449 to 453 inclusive. All of these tests are unimportant. In most research problems it is frequently necessary to devise new methods of testing, and special apparatus.

QUESTIONS

1. Name the standard physical tests for portland cement.
2. Give the standard requirements for the tests given in (1).
3. What is the relative importance of the tests given in (1)?
4. What constitutes grounds for rejection of a given cement?
5. Explain the quartering process as applied to the sampling of cement.
6. How is unsoundness of cement usually manifested?
7. What is meant by the term "normal consistency of cement"?
8. Why is it necessary to determine the normal consistency?
9. What are the two methods used to determine the time of setting?
10. What are the reasons for the tension test of cement?

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Materials of Engineering Construction

Assignment 13.

Civil Engr-8A. Professor C.T. Wiskocil

CONCRETE AGGREGATES

Introduction:- Study Article 454; it is important. There is a growing tendency among engineers to specify the consistency and strength requirements for concrete on various portions of a job, and to give the contractor an opportunity to furnish concrete of required strength according to his own methods.

DEFINITIONS

Study Articles 455 to 464 inclusive. All the terms used in the discussion of mortar and concrete are defined and it is necessary that they be thoroughly understood.

Mortar:- As defined in Article 455, mortar is essentially a mixture of fine aggregate, which is usually sand, cement and water.

Concrete:- Concrete is defined in Article 456. It consists of a large bulk of inert materials in a finely divided state, bound together by a comparatively small amount of cement. The amount of water used in mixing the ingredients is of great importance. Concrete is frequently named according to the kind of aggregate used, as crushed-stone concrete, gravel concrete, cinder concrete and rubble or cyclopean concrete.

Cement:- Cement has been previously defined. In this text only portland cement concrete is discussed. Bituminous concrete is used principally for the surfacing of roads and highways.

Aggregate:- As stated in Article 458 aggregates are divided by the 1/4 inch screen. Those that pass, are classed as fine aggregates and those that are retained are called coarse aggregates. Sand is the principal fine aggregate, while crushed stone and gravel are the predominating coarse aggregates.

Silt:- See Article 459. Silt is usually considered as the fine material which passes a No. 200 sieve. In rich mixtures silt is an undesirable ingredient and is classed as an impurity. A certain amount of silt, however, will benefit or improve the strength of lean mixtures.

Specific Weight:- This term is defined in Article 460. It is the weight in pounds of a definite volume, usually specified as one cubic foot. Since there are no standardized methods for its determination it is necessary to state the conditions under which it is determined. The moisture content as shown in Figure 5 on page 418 is an important factor in the case of fine aggregates. For coarse aggregates the shape and size of the measuring box affects the specific weight. The method of filling the measure or of compacting the aggregates into it are important for both fine and coarse aggregates.

Voids:- Voids as described in Article 461 are the spaces between the particles of aggregate. The void space is always expressed as a percentage. The two methods of determining the void space in an aggregate are described in this article. There is a direct relation between the specific weight and the percentage voids.

method of determining the percentage voids the first term in the numerator gives the weight of a cubic foot of solid material, the second term gives the actual weight of a cubic foot of the aggregate; the difference is, therefore, the amount of void space, which, when divided by the first term, gives the percentage void spaces.

Mechanical analysis:- The first paragraph in Article 462 and the second paragraph on page 411, which describes the method of making a mechanical analysis, are the most important. All scientific methods of selecting and proportioning aggregates are based on mechanical or sieve analyses. The amounts passing or retained on each sieve in the series are expressed in percentage and usually put in the form of a diagram similar to that on page 417.

Yield:- The customary method of determing yield is described in Article 463. The minimum yield obtained by varying the proportions of given aggregates, but keeping the proportion of cement to total aggregate constant, is used as a means of proportioning concrete aggregates. This method will be discussed in the next assignment. See page 429. Yield is frequently determined in investigations on concrete. It is taken as the ratio of the volume of concrete produced by a given volume of mixed aggregates. The volume of the concrete is measured when the specimens are removed from the molds. For 1 to 6 concrete the yield is usually about unity (1.0) but for rich mixtures, one part cement to two parts sand, it may increase to 1.3. For lean mixtures, such as 1 to 9, it may be considered as being unity. Additions of hydrated lime cause an in-

crease in the yield of the usual concrete mixtures.

Density: As defined in Article 464, density is the ratio of total solid material in the concrete to its volume. The volume of the concrete is determined after it has hardened. It is one minus the void space when the latter is expressed as a ratio of voids to total volume. The density of 1 to 5 mortars is about .71, while for 1 to 5 concrete having aggregates up to 1 1/2 inch it may increase to about .83 Density is affected by the richness of the mix and the amount of water used in the mixing.

CHARACTERISTICS AND PROPERTIES OF FINE AGGREGATE

Importance of good aggregate is emphasized in Article 465. The last sentence in that article is important. What it says is this: the best criterion for the suitability of a given aggregate for concrete is actually to make some concrete with the aggregate and test it. This means that the value of a fine aggregate cannot be determined by a mortar test.

Sampling aggregate:- Read Article 466. Considerable judgment is required in securing a representative sample from a sand or gravel deposit. Care is necessary in sampling material that is piled. This is intimated in the last paragraph in the article.

Requirements for fine aggregate:- Study Article 467. The last sentence in the article is particularly important. Note that the sharpness of sand grains is not essential. At one time all specifications stated that the sand grains should be sharp. When it is necessary to use an untried sand, which appears to have a satisfactory grading and hard grains, its suitability can be quickly

estimated by the color test described at the bottom of page 415. The presence of organic matter which might prevent the setting of the cement can be readily detected by this method. On important work an untried sand should not be used.

Composition of particles:- Read Article 468, and study the last paragraph, which gives a list of some of the objectionable minerals in fine aggregates.

Impurities:- Study Article 469. A sufficient number of tests have been made to substantiate the statements made in the first paragraph regarding clay. From the discussion thus far it is evident that strength tests on the finished concrete would prove the suitability of given aggregates without tests for impurities.

Gradation of the sizes of the particles:- Study Article 470 and the curves in the diagram on page 417. Stone screenings are generally not as desirable as sand for fine aggregate for concrete, because they decrease the plasticity of the concrete, and if the plasticity of the mixture is brought to the desired point with water the strength of the concrete will be decreased.

Voids and specific weight:- Study the first two paragraphs of Article 471, and read the remainder of the article. Remember the general tendency of the curves in diagram 6. The voids in a saturated sand my be equal to or lower than those in the dry sand. The moisture content must be known when the voids are determined. The actual amount of fine sand, containing two to ten percent moisture, in a cubic foot of the material is much less than it

would be if the sand were dry or saturated.

Remember these average values for sand: Specific gravity, 2.65; voids, 30%; weight in lb. per cu. ft., 110.

Mortar tests:- Study the second paragraph in Article 472 and read the remainder of the article. In comparing mortars of given proportions it is necessary to mix them so that they have the same consistency. The consistency of sand mortars is not so easily determined as that of neat cement paste. The Vicat apparatus is not satisfactory and other methods must be resorted to; one of them is outlined on page 420. Compressive tests on cylindrical specimens are most satisfactory. The molds for these specimens are 2 inches in diameter and 4 inches long.

CHARACTERISTICS AND PROPERTIES OF COARSE AGGREGATE

Requirements for coarse aggregate:- Read Article 473. Roughly cubical or rounded stones are preferable to those of other shapes. The use of the different stones as concrete aggregate has been given in a previous assignment.

Characteristics and properties of broken stone:- Read Article 474. For unreinforced concrete the usual size of coarse aggregate varies from 1/4 to 1 1/2 inches. The maximum size of particle is smaller for reinforced concrete, usually being limited to that which will pass through a 1 inch ring. If the amount of reinforcement is large and closely spaced, as was the case in the concrete ships, the maximum size of aggregate is still smaller.

Table 2 on page 423 is interesting in that it shows the effect

of jarring and vibration caused by hauling, on the specific weight of crushed stone. This increase may be expected in the case of any coarse aggregate as was intimated under the discussion on specific weight.

The diagram on the upper part of page 423 will be referred to when proportioning is discussed in the following assignment.

Characteristics and properties of gravels:- Read Article 475. Gravel, when properly graded and otherwise satisfactory in regard to absence of impurities and hardness of material, makes an ideal coarse aggregate for concrete.

Broken stone and gravel compared:- Study Article 476. Either class of aggregate may be perfectly satisfactory and neither can be said to be entirely superior to the other.

Miscellaneous aggregates:- Read Article 477. During the development of the concrete ship various light-weight aggregates, such as crushed brick, slag, volcanic scoria and pummice, were used. The aggregate finally adopted was a specially burnt clay or shale which was full of nonconnecting cells so that it made a strong aggregate of light weight. It was crushed to two sizes; the coarse ranged from 1/2 to 3/16 inches, and the fine passed a screen with 3/16 inch round openings. The concrete was rich, being made in the proportions of 1 part cement to 2 parts total aggregate. In addition a special fine-ground cement, 90% passing the No. 200 sieve, was used. The concrete weighed about 118 lb. per cu. ft. instead of the usual 150 lb. per cu. ft. of ordinary concrete. Its strength was from 3,500 to 5,000 lb. per sq. in. in 28 days. It was necessary

to make the concrete rich in cement because, in order to pour it in thin sections with heavy reinforcement it had to be very wet. A slump of 9 inches was specified.

The artificial aggregate was essentially a bloated brick. It was made of basic clay or shale which when subjected to a temperature of about 2,000 degrees becomes plastic and sears over on the surface. The coating which is formed retains the gases generated by the decomposition of the contained chemicals. This expanding gas blows the clay full of cells and bloats it to several times its original volume.

QUESTIONS

1. What is concrete?

2. Define density as applied to concrete.

3. How is the void space in concrete aggregates determined?

4. What is the relation between the voids and the density of concrete?

5. What is the value of the mortar test in determining the suitability of a given sand as a fine aggregate for concrete?

6. What is the use of the so-called color test?

7. How would the proportions of a mortar be affected if a damp sand, say one having about 6% moisture, and the cement were proportioned by volume?

8. What are the principal requirements for a coarse aggregate for concrete?

9. Compare the merits of gravel and broken stone aggregates.

10. Name some aggregates other than stone and gravel that are used in the making of concrete.

UNIVERSITY OF CALIFORNIA EXTENSION DIVISION

Correspondence Courses

Materials of Engineering Construction

Civil Engr-8 A. Professor C.T. Wiskocil

Assignment 14.

PROPORTIONING OF CONCRETE

The principles of proportioning:- Study Article 478. The statements made in this article are a summary of the discussion of strength and permeability of concrete which will be taken up in assignments 16 and 17.

Proportioning concrete is a subject which involves the question of relative costs as affected by the selection and combination of aggregates. When different materials which have different characteristics are available, the proportioning involves the selection of those which are best suited for the purpose. After the aggregates of proper size and grading have been selected it is necessary to decide upon the proportions, or the ratio of cement to total aggregates, so that concrete of proper strength may be made. The consistency, as affected by the quantity of mixing water used, must also be considered. Frequently the concrete must be very plastic so that it can be poured into the molds. If high strength is an additional requirement the concrete must contain more cement than would be required to produce the same strength if drier concrete could be used. Proportioning of concrete must take into account all of these factors.

The first methods of proportioning concrete were based on the theory that the maximum strength and imperviousness were secured

when the concrete was of maximum density. According to these methods there were: arbitrary proportions, proportions based on voids, proportions based on minimum yield, and proportions based on mechanical analysis. The more recent methods, one based on surface areas of materials and the other based on fineness modulus and water ratio, do not use the maximum density criterion. These methods will now be explained in detail.

The measurement of proportions: Read Article 479. The tendency at the present time is toward greater accuracy in the measurement of concrete aggregates. The wheel barrow is the measuring device in general use but automatic measuring scales are on the market. These devices can be economically used only on large jobs. In the laboratory the materials are proportioned by weight, unless otherwise specified.

Arbitrarily selected proportions:- Study Article 480. Concrete proportions are usually stated by volume. A 1:2:4 mixture, one part cement to two parts fine aggregate to four parts of coarse aggregate, is standard. In this method it is assumed that there are generally about 50% voids in the coarse aggregates. The amount of fine aggregate (sand) specified is, therefore, one half the volume of the coarse aggregate even though the cement and water used will bring the resultant mortar to more than 50% of the volume of the coarse aggregate. The ratio of volume of cement to volume of fine aggregate is determined by the engineer on the basis of past experience and the strength the concrete must have. Arbitrarily selected proportions seldom exceed 1:4:8, which is a lean

mixture used only in large masses for unimportant work. Arbitrary proportions are less than 1:1-1/2:3, which is a rich mixture used where strength is a prime requirement. As indicated in the text the proportion of fine aggregate is sometimes varied according to the proportion of void space in the coarse material. In general, arbitrary proportions are made without regard for the size and grading of the aggregates; the method is, therefore, not scientific and yields satisfactory results only in the hands of those experienced in its use. In most instances the cement is not economically used, Yet this method is probably more widely employed than any other at the present time.

Proportions based on voids:- Study Article 481. While this method is not in general use it is believed, by those who use it, to be quite scientific. The text points out the inaccuracies in the method and some of the errors in the assumptions upon which the method is based.

Proportions based on minimum yield:- Study Article 482. The method described in this article is sometimes called "Proportions based on Maximum Density" and "Proportions by Trial Mixtures". It is a very satisfactory method and gives immediate results if only one fine and one coarse aggregate are available. It is not well adapted for the selection of aggregates when there are several of each type available. When the method is applicable it deals with the materials mixed under field conditions and yields good results.

Proportioning by mechanical analysis:- Study Article 483.

The methods of proportioning concrete aggregates previously described might be classed as cut-and-try methods. The use of mechanical or sieve analysis of aggregates gives the engineer an opportunity to make intelligent use of the materials at his disposal and brings proportioning out of the rule-of-thumb class into the scientific field.

Mechanical analysis was probably first used to proportion concrete aggregates by Fuller and Thompson in 1907. Their method of proportioning is described in the text in Article 483. This method will, in general, give a dense, impermeable concrete. It permits the determination of the best proportions of coarse and fine aggregates; it also enables the engineer to tell what sizes of materials should be added or what sizes should be screened out to improve the grading of given aggregates. By this process he is able to obtain an ideally graded aggregate which, in large work, may also be found to be economical, inasmuch as the cost of screening and handling the aggregates may be less than the cost of the additional cement that would be required to produce concrete of equal strength and imperviousness from ungraded materials. The cement ratio is usually assumed, being taken as the ratio of cement to total aggregate as 1:7. The ratio of cement to sand and coarse aggregate may come out as 1: 2.3:4.7, depending upon the combination that most nearly approaches the ideal curve. The proportions may be expressed by weight or volume.

Fineness modulus method for proportioning concrete:- Read Appendix B, pages 815 to 824 inclusive. This information is given in more detail by Duff A. Abrams in Bulletin 1 of the Structural Materials Research Laboratory, Lewis Institute, Chicago DESIGN OF CONCRETE MIXTURES. Abrams' method of proportioning is based upon the principle that with given concrete materials the quantity of mixing water used determines the strength of the concrete so long as the concrete is plastic and the aggregate is not too coarse for the quantity of cement used. The relation between strength and water ratio is shown in Figure 1 on page 816. Water ratio is the usual designation for the ratio of volume of water to volume of cement as defined on page 816. Figure 1 is very important. It is unfortunate that the same symbols should have been used to designate two different mixes. If it is remembered, however, that the concrete must be plastic, the difficulty will be overcome. Notice, for instance, that x is used to designate a 1:2 mix as well as a 1:9 mix. The symbol, however, could not designate the latter mix in the upper part of the curve. In this part, it indicates strengths of approximately 6,000 lb. per sq. in, and since the corresponding water ratio is 0.50, very dry mix would result if the proportions were 1:9. These x's must, therefore, represent the 1:2 mix. The 1:9 evidently is represented by those marks under 1,000 lb. per sq. in. and the 1:2 by those above that strength.

The amount of mixing water used must be carefully considered. This factor has not been taken into account in those methods of proportioning so far discussed in the assignment. Figure 1 indicates

the effect of excess water. A slight excess of water may reduce the strength as much as 40%. Abrams' tests show that the strongest concrete is that which requires the least amount of water in terms of cement (water ratio) to produce concrete of the required consistency. With a given aggregate and increasing amounts of cement - that is, increasing the richness of the mix- the water required to produce a plastic consistency will give a decreased water ratio. This is in accordance with previous tests which show that for the same aggregate the richer mixtures are the strongest.

While the effect of water on the strength of concrete had been known in a general way Abrams was the first to express the relation in the definite terms of water ratio and make tests covering a wide range of aggregates and mixtures. He found that aggregates of considerable difference in grading may give the same strength but that there is a definite relation between the grading of the aggregate and the quantity of water required to produce a plastic concrete. The size and grading of the aggregate and the proportion of cement all affect the amount of water necessary to produce a workable concrete. The fineness modulus, which is defined on page 815 - see also table 1 on page 817, is a measure of the grading of a material. A coarse aggregate may have a fineness modulus over 7.00 while a fine sand may be as low as 1.25 The amount of water is required to wet an aggregate of a given fineness modulus is always the same irrespective of its grading. Study the relation between fineness modulus and strength as given in Figures 2 and 3 on pages

817 and 818 respectively.

Read carefully the outline of method of designing concrete mixes beginning on page 821. Add the following to the paragraph marked 1. Experience or trial is the only guide in determining the relative consistency of concrete necessary in the work. A relative consistency of 1.00 is dry and requires tamping. Concrete having a relative consistency of 1.10 is about the driest that can be used for concrete road construction. For most reinforced concrete construction the relative consistency should be about 1.20; and it should never be above 1.25

It is not expected that you be able to design a concrete mixture by Abrams' method, but you should be able to tell in a general way how it is done. Remember the following criterion: Use the smallest quantity of mixing water that will produce a concrete of the required plasticity.

Proportioning by surface areas:- This method of proportioning is not described in the text. It was proposed by L.N. Edwards, who applied his theory to the proportioning of mortars. R.B. Young later used the surface area method to proportion concrete aggregates. The underlying principle assumes that the strength and other properties of mortars and concretes are dependent upon the amount of cement used in relation to the total surface area of the aggregates. The use of the method is simplified by tables prepared by Edwards and Young from which the surface area of an aggregate can be determined when its sieve analysis is known. They have also made

diagrams which give the relation of strength to ratio of cement to surface area. These latter diagrams have been prepared from actual test data. When several aggregates are available, the best combination, which is also the most economical, is the one which has the least surface area for a given volume. The effect of water on the strength has been taken into account in this method of proportioning. When the method is used in the field, as it has been, very successfully, by R.B. Young, the water content and cement content are changed in the same proportion until the desired consistency is obtained. This procedure does not effect the strength of the mix. It is not always necessary to change the water ratio determined in the laboratory.

Comparison of methods of proportioning concrete:- The methods of arbitrarily selected proportions, proportioning by voids, and proportioning by minimum yield do not require a laboratory study of the aggregates, but they may be wasteful of cement. When high strength, imperviousness and resistance to abrasion are required, the proportioning must be done with more care and the methods based upon sieve analyses yield economical and satisfactory concretes. Abrams' Fineness Modulus method and the Surface Area Method are prooably most satisfactory, in such cases, since they were determined by tests in which a wide variety of aggregates was used. For instance, Fuller and Thompson's method,which led to the conclusion that concrete of maximum density was the strongest, was based on tests of a very limited number of aggregates. Abrams' tests, in

the determination and study of the Fineness Modulus Method, based on a much wider selection of concrete aggregates proved on the contrary that concrete of maximum density was not always the strongest.

Proportions commonly used in different constructions:- Read Article 484. Do not attempt to memorize the tabulation given in this article. The 1:2:4 concrete is a common standard. Sometimes a strength specification of 2,000 lb. per sq. in. at 28 days, is made.

Testing the quality of concrete:- Strength tests are most valuable in determining the quality and uniformity of concrete. The usual specimen is a 6 by 12 inch cylinder, tested at 28 days. The specimens should be poured with concrete taken from the mixer or just before it is placed in the structure. Read Article 485.

Quantities of materials required for one cubic yard of concrete:- Read article 486. Omit Tables 4 and 5. Remember Fuller's rule as given on page 434.

Interpretation of the meaning of proportions:- Study Article 487; it is important. The statements given in this article will be evident to the student who has studied the assignments up to this point. If two cubic feet of sand are mixed with four cubic feet of rock it is obvious that the combination will not fill a six cubic foot measure. When the proportions of fine and coarse aggregates are stated, the specifications should read --- "each of the constituent materials shall be measured separately".

QUESTIONS

1. What is meant by proportioning as applied to concrete aggregates?

2. How are the relative amounts of fine and coarse aggregates determined in the method called arbitrary selection?

3. What determines the ratio of cement to total aggregates in the method of arbitrary selection?

4. What are the errors in the assumptions used in proportioning concrete aggregates by voids?

5. Discuss the adaptibility and limitations of the proportioning of concrete aggregates by trial mixtures.

6. Describe Fuller and Thompson's method of proportioning concrete.

7. What are the advantages of methods using mechanical analyses over earlier methods in which such analyses were not used?

8. Define water ratio as used in Abrams' method of proportioning.

9. What is meant by the term fineness modulus?

10. How does the amount of mixing water used affect the strength of concrete?

11. What is the surface area method of proportioning concrete?

12. Which of the methods discussed is the most widely applicable and why?

13. Approximately how much cement, sand, and stone will be required to make 20 cubic feet of concrete if the proportions are 1:2:4?

UNIVERSITY OF CALIFORNIA EXTENSION DIVISION
Correspondence Courses

Materials of Engineering Construction

Civil Engr.-3 Assignment 15 Prof. C. T. Wiskocil

MIXING, PLACING AND CURING OF CONCRETE.

Principles of proper mixing.- Study Article 488. The materials should be uniformly distributed throughout the mass so that the mixture is homogeneous and uniform in color. The same amount of water should be added to each batch in order to maintain the desired consistency.

In hand mixing the water is usually measured in buckets while machine mixers are provided with water-measuring devices.

Hand mixing.- Read Article 489. The following specifications were taken from the latest reports of the A.S.T.M.: "When hand mixing is authorized by the engineer it shall be done on a water-tight platform. The sand shall be spread on the platform and the cement spread evenly over the sand. The material shall then be shoveled into a cone shaped pile by casting centrally on the pile. This pile shall then be divided by casting into two or more cone shaped piles and the operation of dividing and reuniting continued until the batch is uniform in color. Only sufficient water to produce the desired consistency shall then be added by sprinkling as the batch is turned. The coarse aggregate previously moistened shall then be mixed with the mortar in the manner specified for mixing sand and cement." This method is productive of better results than can be secured by the methods commonly used.

Machine mixing.- Study Article 490. The A.S.T.M. specifications read, "Mixing, unless otherwise authorized by the engineer, shall be done in a batch mixer of approved type....." The Continuous mixer, while it can be operated rapidly and cheaply, rarely gives a uniform product. Since it cannot be relied upon, the batch mixer is preferable.

The time of mixing is specified as follows: "The mixing of each batch shall continue not less than 1 minute after all the materials are in the mixer, during which time the mixer shall rotate at a peripheral speed of about 200 feet per minute....." Although the data given in the text, shown in Figures 9 and 10, would indicate that a longer period of mixing would be desirable, and the A.S.T.M. formerly recommended 1 1/2 minutes as the mixing time, recent tests seem to warrant the minute mix.

Mixing produces a change in the consistency of concrete, the water content remaining constant. The change is particularly marked between 30 seconds and 1 minute, but the additional change after 1 minute is slight.

It is possible to obtain the same degree of plasticity (consistency) by mixing for 1 minute as would be obtained by mixing for 1/2 minute with 25% more water. Contractors sometimes resort to the shorter mixing periods in order to save time, and add more water in order to bring the concrete to the desired consistency. The A.S.T.M. specifications, however, do not permit the retempering of mortar or concrete, that is the remixing with or without additional cement, aggregate, or water.

Hand vs. machine mixing.- Read Article 491. Good mixing can be secured by hand as well as machine mixing; the former however, requires heavy labor and is usually not thoroughly done. For all except the smallest jobs, machine mixing will be less expensive than hand mixing.

The tests referred to in this article would indicate that hand mixing is inferior to machine mixing. With reference to hand mixing as it is usually done , this is probably true. The last sentence in the article, which states that the hand mixed concrete referred to in the test required more water to bring it to the consistency of that mixed by the machine, shows that the mixing by hand had been slighted. If the hand mixing had been thoroughly done there would have been no marked difference between the concrete produced by the two methods.

Handling of concrete.- Read Article 492. The fundamental principle in the handling of concrete is that there must be no opportunity afforded for a segregation between the mortar and the course aggregate.

Besides the methods described in the text, concrete is transported in large motor-trucks from a central mixing plant in road construction. Sometimes the hauls are very long. In order to determine the effect of such transportation the Bureau of Public Roads has recently made a series of tests in which the concrete was hauled for diffenent periods, up to 3 hours. They found that after 45 minutes of hauling the concrete became too stiff for hand finishing, but that the strength was not reduced as long as the concrete remained workable.

Concrete should not be deposited under water if it is practical to exclude the water by means of cofferdams. There is always uncertainty in depositing concrete under water even if the methods described in the text are used. If it is impractical to use other methods concrete should be placed under water only under experienced supervision. This is particularly true in the case of sea water. The usual methods in which the tremie, drop-bottom buckets, and bags are used, are described in the text.

Placement of concrete.- Read Article 493. Concrete should be placed in the forms in its final position so as to make re-handling unnecessary. It should be placed in uniform horizontal layers and not allowed to flow down a slope so as to permit a segregation of fine and coarce materials. During and immediately after depositing, the concrete should be thoroughly compacted by spading or rodding. Some compacting is necessary to make the concrete flow into the corners of the molds and around the reinforcement since it is usually mixed with as little water as possible. The days of wet, soupy concrete which did not require rodding are over. Relatively dry concrete can be used in the construction of concrete pavements since power-driven tampers and metal rollers can be used to compact it. Concrete used in reinforced construction must be more plastic so that it can be properly placed.

Cement mortar can be deposited by an apparatus known as a cement gun. This device is described on page 444 of the text. The cement gun is being widely used. It produces a dense strong mortar.

Joining old and new work.- Read Article 494. If work is not continuous, joints cannot be avoided. In making joints every precaution should be taken to make the bond as strong as possible. The methods of bonding are described in this article. Laitance is mentioned. It is a whitish scum which comes to the surface of wet concrete. Laitance is formed when concrete is deposited under water or when water comes to the surface of the concrete which has been mixed with an excess of water. It is composed of finest particles of cement and the dirt in the aggregates. While the composition of laitance is practically the same as that of cement it does not have the same properties. It does not harden or acquire much strength and consequently if it is not removed it prevents the bonding of successive layers of concrete.

Forms.- Read Article 495. Forms should be sufficiently tight to prevent the leakage of mortar and they should be so braced andtied together as to maintain their position and shape.

Before concrete is deposited in the forms all debris should be removed from the place to be occupied by the concrete. The forms should be cleaned and thoroughly wetted or oiled to prevent absorption of water from the concrete. Steel has been used for some time for forms for concrete pipe, tunnels, sewers, curbs, retaining walls and dams, and it is gradually replacing wood for formwork in standardized building construction.

Read the information regarding the pressure of wet concrete against the forms as given on page 447. More recent experiments give lower values. The most reliable are given in POURING AND

PRESSURE TESTS OF CONCRETE by Slater and Goldbeck, U.S.Bureau of Standards, Technologic Paper No. 175. Their principal conclusions are: (a) The maximum pressure against the forms during pouring of concrete was found to be equivalent to that of a liquid weighing about 124 lb. per cu. ft. (b) The maximum pressure was found to be that due to the head of concrete existing at the end of about 40 minutes. After that time the pressure gradually decreased in spite of increasing the head of concrete. These data are of value in the design of forms.

The time for removing forms is determined by the strength of the concrete. As indicated in this article the strength of the concrete can be found only by actual tests. The removal of the forms from concrete structures that have not developed sufficient strength has resulted in many failures. On the other hand, much money value is sacrificed if the forms are left on too long. Weather, position of the form, quality of the cement, and the load are the principal factors which influence the time of removal of the forms. Warm, dry weather hastens the setting and hardening of concrete, while cold, damp weather retards hardening, Forms for horizontal members, such as beams, should remain in place longer than forms for vertical members, such as columns and walls. The forms may obviously be removed sooner from concrete made with quick-hardening cement than from normal concrete. When the load carried by a member is nearly all live load such as machinery, equipment, and people, the forms may be removed sooner than when the total load on the member is largely dead load. For this reason roof forms and

which comes upon
the structure after

top-story columns are left on longer than those for other floors. The following table is abstracted from Hool and Johnson's CONCRETE ENGINEER'S HANDBOOK:

Removal of forms

	Above 60° F.	50-60° F.	40-50° F.
Column Sides	Within 3 days	5 days	10 days or more
Beam Bottoms	Within 14 days	18 days	24 days or more

Expansion joints.- Read Article 496. Concrete shrinks when it sets in air and expands when it sets in water. After it has set, changes in moisture content cause volume changes. Concrete expands when it is wet and contracts when it dries out. Expansion and contraction are also caused by heating and cooling respectively. The forces which produce volume changes may counteract one another so that there will be no effect on the concrete. They may also act together or separately and cause volume changes which become evident as expansion and contraction. The change in length in 100 ft. of concrete is about 0.8inches per 100 degrees Fahrenheit. In contraction, this produces cracks in walls, walks and pavements. In expansion, it buckles curbs and walks unless expansion joints are provided. Long stretches of wall may be built without expansion joints provided that enough steel is put in to hold the concrete together. The steel does not stop the movement but it distributes the total change in length and produces a large number of very fine cracks which do no damage. The A.S.T.M. specifications provide that "structures exceeding 200 ft. in length andof width less than

about one-half the length, shall be divided by means of expansion joints, located near the middle, but not more than 200 ft. apart, to minimize the destructive effects of temperature changes and shrinkage....." When such expansion joints are used they should be arranged to separate completely the parts of the building and should extend from the bottom to the top of the structure. An expansion joint should separate all parts such as beams, columns and slabs from the main part of the structure. When expansion joints are placed in retaining walls they should be spaced about 30 ft. apart.

Curing.- Read Article 497. The process of keeping concrete damp is called curing. Concrete is cured by immersion, sprinkling and the use of steam. Hydration of the cement goes on after the concrete has hardened, so that it is necessary to prevent it from drying out too rapidly. Allowing the forms to remain in place helps to retain the moisture. Newly laid concrete pavements are protected from the direct rays of the sun by means of canvas and after the concrete has set, it is covered with moist earth or flooded with water.

Concrete products such as described in Chapter XV are cured by the three methods mentioned above, immersion, sprinkling and the use of steam. The American Concrete Institute specifies protection from the sun andstrong currents of air for at least 7 days; continuous sprinkling andmaintenance of a temperature of not less than 50 degrees Fahrenheit and storing in the yards for about 21 days before shipment. For steam curing, their specifications

Engr.-3 Materials of Engineering Construction. Assn. 15,page 9. read, "The products shall be removed from the molds when the conditions permit and shall be placed in a steam curing chamber containing an atmosphere of steam saturated with water for a period of at least 48 hours. The curing chamber shall be kept at a temperature between 100 and 130 degrees Fahrenheit. The product shall be removed and stored for at least 8 days."

Protection against freezing.- Read Article 498. Concrete should not be mixed or deposited at a freezing temperature unless precautions are taken to overcome the effects of low temperature. Work may be carried out during freezing weather by heating the materials and the structure or by the addition of some substance to lower the freezing-point of water. Wherever the temperature drops to 35 to 40 degrees Fahrenheit the materials should be heated. After concrete has been placed it should be protected against the cold for 48 hours to 5 days, dependingupon the temperature. When important structures must be constructed during periods of low temperature they are completely enclosed with tarpaulin or heavy canvas even though they may be large buildings. The interiors are then heated, as explained in the text.

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QUESTIONS

1. What constitutes proper mixing?
2. Describe the method of hand mixing recommended by the A.S.T.M.
3. What are the principal factors that should be considered in the purchase of a concrete mixer?

QUESTIONS, con.

4. How long should concrete be mixed when a batch mixer is used?

5. What is the fundamental principle in the transportation and deposition of concrete?

6. What methods are used to deposit concrete under water?

7. What precautions should betaken in bonding to old concrete work?

8. What approximate lateral pressure is exerted against the forms by fresh concrete?

9. What causes concrete to shrink? What is the effect of shrinkage and how is it overcome?

10. What precautions must be taken when concreting at or below freezing temperatures?

11. What is meant by curing concrete?

12. Why is a batch mixer considered better than a continuous mixer?

13. In what way may the quality of concrete be impaired by methods of placing in ordinary construction?

UNIVERSITY OF CALIFORNIA EXTENSION DIVISION

Correspondence Courses

Materials of Engineering Construction

Civil Engr.-8 Assignment 16. Professor C.T.Wiskocil

PHYSICAL PROPERTIES OF MORTAR AND CONCRETE.

Introduction.- Read Article 499. While the effect of the important factors which influence the physical properties of mortar and concrete are discussed in this assignment it should be remembered that in any investigation all factors are not known, and that it is consequently not possible to control them all properly, and that the results,therefore, should be taken as being indicative only. In many of the data given in the text, no attempt is made to state the conditions under which the tests were made. This information is frequently omitted even from the original publications from which the data were compiled.

Strength of mortars.- Read Articles 500 to 506 inclusive. The principal use for mortar is in the construction of masonry. When strength is required in stone, brick or terra cotta structures, portland cement mortar is used. Cement mortars in various proportions are also used for stucco. Stucco may be defined as a material used in a plastic state to form a hard coating for the exterior walls or other surfaces of any building or structure. Mortar is relatively unimportant when compared to concrete.

The effect of proportion of cement on the strength of mortars is discussed in Article 500 and shown in Figure 1 on page 452. Compare the strength of neat cement given in Figure 14 on page 332

with the compressive strength given for neat cement on page 452. Compare also the figure on page 334 with that on page 452. The strength of neat cement as well as mixtures of cement and fine aggregate varies with the brand of cement used - cements do not all have the same cementing value. Other factors which affect the strength of cement and cement mixtures are: the amount of water used in mixing, the conditions of storage and testing and the gradation of the sand(as shown in the figures on pages 452/453 and 454.) Because of the relative unimportance of mortar as a structural material make no attempt to remember the data in Article 500 to 502 inclusive.

Probably the most comprehensive tests of cement mortars are reported in Technologic Paper No. 58 of the U.S.Bureau of Standards. From this publication the following information is taken "(a) The quality of a sand cannot be judged from its gradation alone.(b) For most fine aggregates the highest strengths are obtained with those having a gradation of particles approaching a straight line, but often materials having a gradation varying widely from a straight line will give high strength in mortars. (c)No fine aggregate should be rejected because of its silt content (determined by washing or assuming the material passing the No. 200 sieve as silt) as it may be advantageous even in relatively large quantities or detrimental in small quantities, depending upon its form, character and distribution.(d)The only satisfactory method of determining the

value of a fine aggregate in mortar mixtures is to test it in the mixture, in the proportion to be used, exposed to the same conditions as in the proposed structure." These above remarks are of importance in the consideration of mortar.

The strength in compression and in cross bending can be estimated with sufficient accuracy from the average strength of neat mortar, 10,000 lb. per sq. in. (compression) and 1,000 lb. per sq. in.(cross bending), and from the general shape of the curves on page 452, which give the relation between strength and proportion of cement to aggregate. A 1:6 mortar has an approximate compressive strength of 1,000 lb. per sq. in. and an average transverse strength of 300 lb. per sq. in.

The effect of the amount of mixing water on the compressive strength of mortars is similar to that shown on page 816 in the case of concrete. This relation for neat and 1:3 mortars is shown in Figure 10 on page 33, Bulletin No. 8, of Structural Materials Research Laboratory, Lewis Institute, Chicago.

Mica decreases the compressive strength of mortar. Recent experiments made by Professor Abrams at Lewis Institute bear out this statement but his tests indicate that the decrease is not as marked as that found by Wills. See Article 504.

Tests reported in Bulletin No. 8 of the Structural Materials Research Laboratory, previously referred to, indicate that the use of hydrated lime decreases the strength of cement mortar. About

8,000 tests on briquettes and 2 by 4 inch cylinders were made during this investigation. The tests mentioned in Article 505, since they are few in number, cannot be given as much consideration.

Merely read Article 506 on adhesion of mortars; it is relatively unimportant.

Strength of concrete.- Read Articles 507 to 517 inclusive. The strength of concrete is affected by various factors, the most important of which are: age, proportions of cement to aggregate, kind of aggregate, amount of mixing water, and curing conditions. In view of these variables, good average figures to remember are: 2,000 lb. per sq. in. in compression, 200 lb. per sq. in. in tension and 1,000 lb. per sq. in. in shear at 28 days. At the age of one year concrete is about 2 1/2 times stronger than at 28 days, the usual testing period. Concrete is a brittle material, and as the average values given indicate, is strongest in compression. Its tensile strength is low and is neglected in the design of reinforced concrete structures. The shearing strength of concrete is about 1/2 its compressive strength.

The compressive strength increases with the richness of the mix. The tables on pages 459, 460 and 461 show this fact - but not in a form that can be easily remembered. The following diagram gives average values for soft limestone concrete stored in a damp location. The proportions are the total of fine and coarse aggregates measured separately. The diagram also indicates the normal increase

in strength with age. The dotted curve was plotted from data for gravel, hard limestone or hard sandstone concrete 28 days old, taken from the report of the Joint Committee on Concrete and Reinforced Concrete. The values are based on tests of 8 by 16 inch cylindrical specimens stored under laboratory conditions.

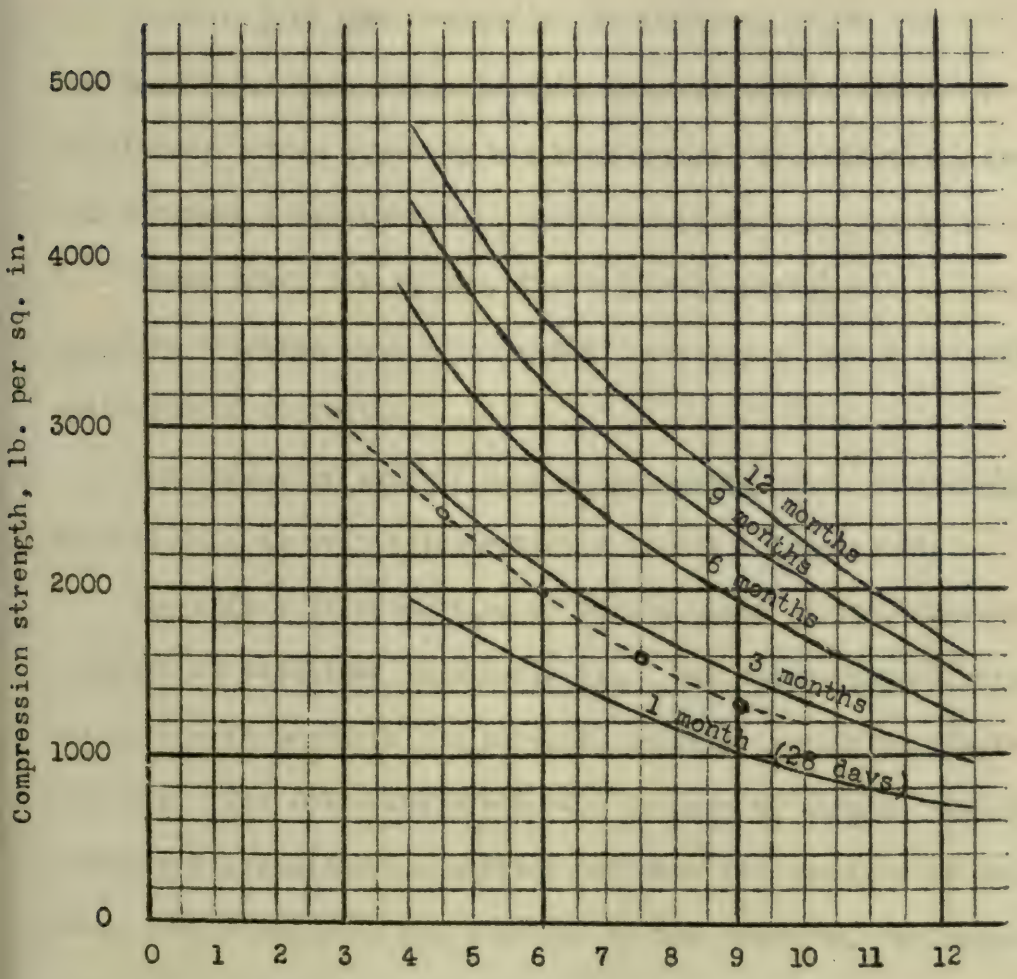
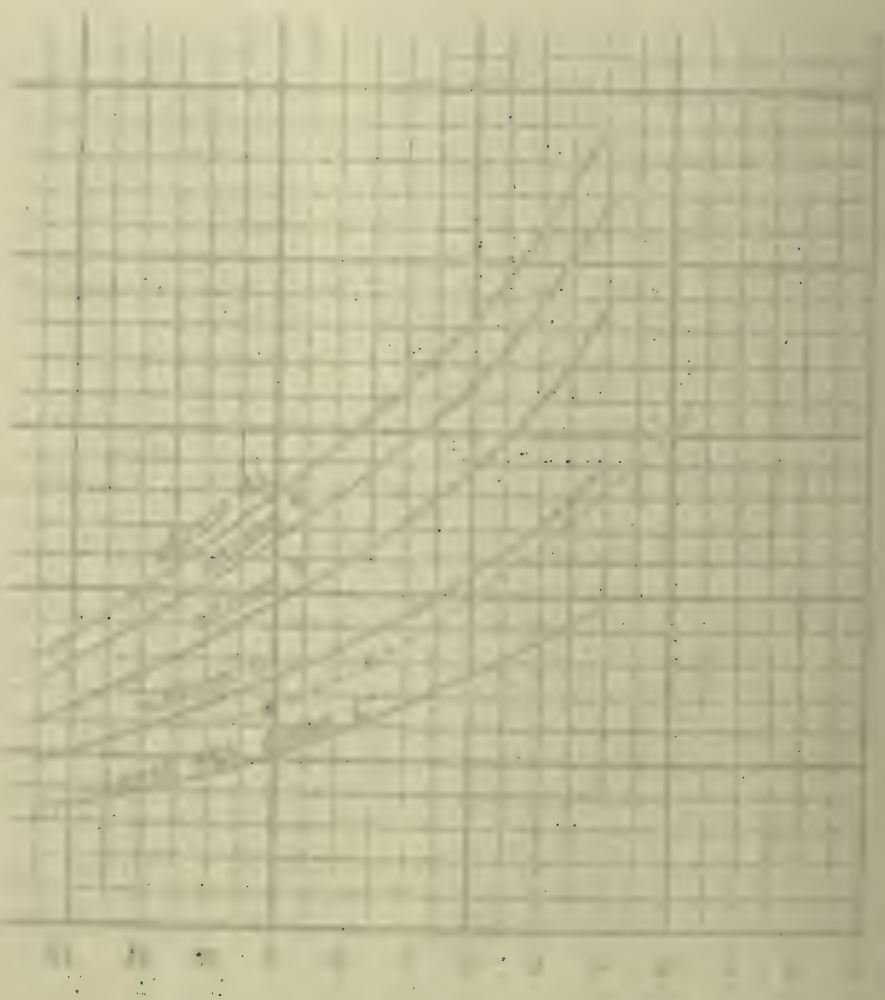


Figure 1



Under ordinary conditions concrete will not gain much strength after one year but if concrete does not dry out its compressive strength increases indefinitely. See EFFECT OF AGE ON THE STRENGTH OF CONCRETE by D. Abrams, A. S. T.M. Proceedings, 1918, page 317. The age-strength relation for mortar and concrete is expressed by the equation

og a + k where S is the compressive strength, a is the age and n and k are constants whose value depends upon the cement and other test conditions. This equation has been derived from tests in American and European laboratories on specimens up to nine years in age.

Since there are so many factors which affect the density-strength relation (see Article 509), density is not a reliable criterion of strength.

The effect of size of coarse aggregate, which is discussed in Article 510, is well illustrated in Figure 3 on page 818.

The effect of proportion of mixing water on the strength of concrete is explained in Article 511. The water ratio - strength relation - is shown in a clear-cut, definite manner in Figure 1 on page 816. The following conclusion is made by Abrams: With given concrete materials and conditions of test the quantity of mixing water used determines the strength of the concrete, so long as the mix is of a workable plasticity.

The information in Article 512 is relatively unimportant. Remember that the tensile strength of concrete is about 1/10 of its compressive strength.

Because of its low tensile strength concrete without steel reinforcement is rarely used where it would be subjected to transverse loads. The discussion on transverse strength in Article 513, therefore, is of little importance.

Read carefully the first paragraph of Article 514. The remainder of the article is not important. Remember that the shearing strength (punching shear) of concrete is about 1/2 of its compressive strength.

The effect of type of aggregate is well illustrated in the Joint Committe Report (previously referred to) from which the following data were taken:

Granite, trap rock	2,200
Gravel, hard sandstone, hard limestone	2,000
Soft limestone, soft sandstone	1,500
Cinders	600

The values given are for compressive strength in lb. per sq. in. at 28days for 1:6 concrete, the fine and coarse aggregates being measured separately.

The conditions under which concrete is cured have a great influence upon its strength. The following statements were taken from EFFECT OF CURING CONDITION ON THE WEAR AND STRENGTH OF CONCRETE, by D.A.Abrams, Bulletin No. 2, Structural Materials Research Laboratory, Lewis Institute, Chicago. "All consistencies of concrete show great increases in strength under favorable curing conditions as compared with specimens which were allowed to dry out at once. The dryer mixes show a more rapid improvement due to storage in a damp place during the first few days than the wetter ones. Even

three days in damp sand results in increase in strength of dryer concretes of about 35% as compared with that of the specimens stored in open air for the entire period. Concrete stored in damp sand and tested damp is about 3 times as strong as similar concrete which had been exposed to room atmosphere for the same period. Protecting concrete from drying out for only 10 days gives an increase in strength of about 75% for the dryer mixes."

Elastic properties of concrete.- Read carefully Article 518. In it the true elastic stress-deformation and gross deformation curves are described. The gross deformation is usually plotted against stress, as indicated in Figures 12 and 13, on pages 476 and 477 respectively. These curves show a decided curvature, concave downward, as stress-deformation curves for other brittle materials do; see Figure 11 on page 710. The elastic stress-deformation relation is of importance in the determination of stresses in structural members under load. Under long time loads, concrete undergoes a greater deformation than it does for the same load applied for a short period, as in the usual testing machine. The gross deformation of a given fiber cannot be used to compute the actual stress; the elastic deformation must be used.

It should be noted at this time, that there are investigators who believe that the stress deformation curve for concrete up to and even over working stresses is a straight line. They show data to support their views and state that in their judgment the curvature in most stress-deformation curves is due to inaccurate apparatus

and technique on the part of the investigator. Note that the stress-deformation curves given in Figure 12 on page 476 are practically straight lines up to 1,000 lb. per sq. in., which is well above working stresses for concrete. Stress-deformation diagrams for tests reported by C.T.Wiskocil in the Report on California Highways - California Automobile Clubs, 1921, part IV, page 18, for concrete whose average compressive strength at 28 days was 2,430 lb. per sq. in., were straight lines up to an average stress of 1,080 lb. per sq. in. For 2,000 lb. concrete the working stresses vary from 450 to 650 lb. per sq. in. depending upon the kind of stress, that is whether it is direct compression or extreme fiber stress in bending.

Read Article 519. The difference between the initial and secant moduli is explained and illustrated. Since these terms are in use, their meaning should be known by the student.

Read Article 520. The modulus of elasticity of concrete varies from about 1,000,000 to 4,000,000 lb. per sq. in. For 2,000 lb. concrete the average value is about 2,000,000 lb. per sq. in., being 1/15 that of steel. This value is used in most design calculations.

Poisson's ratio, given in Article 521, is of value in theoretical discussions and in the determination of stresses in certain types of structures, such as arch-dams. For practical purposes the ratio may be taken as 1/10.

A change in moisture content, as well as variation in direct load and change in temperature, has an important effect on the

deformations produced in concrete. Read carefully the first paragraph in Article 522. Since concrete and steel have practically the same coefficient of expansion they change length at the same rate, and variations in temperature do not cause any stress unless the member is restrained. Changes in moisture content, on the other hand, effect only the concrete, which expands when it absorbs water and contracts when it dries. After concrete sets it ordinarily shrinks a considerable amount. This shrinkage during hardening may be as much as 0.05% in an ordinary structure. Contraction in concrete when it is restrained by an external force, as by other members in a structure or by steel reinforcement, causes stress in the concrete. In reinforced concrete the shrinkage produces stress in the steel, when the reinforcement is less than 1.5% , which may reach ordinary working stresses (16,000 lb. per sq. in.) If the amount of steel reinforcement is greater than 1.5% the stress produced by the drying out of the concrete may reach the ultimate tensile strength of the concrete. The greater the amount of steel, the greater will be the tensile stress produced in the concrete for a given reduction in moisture content. Under atmospheric conditions where concrete is alternately wet and dry the alternation in stress may crack the concrete even if the stress is below the ultimate tensile strength of the concrete as determined in the usual static test. Excessive expansion and contraction can be reduced by waterproofing the concrete.

QUESTIONS

1. What is the principal use for cement mortars?

2. Give the average compressive strength of neat and 1:6 cement mortar when about 1/2 year old.

3. What is the approximate strength of 1:6 concrete (the fine and coarse aggregates being measured separately) in compression, tension, and shear at 28 days?

4. What would be the approximate compressive strength of the concrete specified in question 3 at the age of one year?

5. How does the rate of increase in strength vary for different ages? What influences the increase in strength besides age?

6. Approximately what difference in compressive strength would you expect between (a) concrete exposed to air and (b) the same concrete kept in a damp condition?

7. Draw a curve to show the ititial and secant moduli of elasticity for concrete in compression.

8. What is the average modulus of elasticity for 2000 lb. concrete?

9. What is the approximate working stress used for 2000 lb. concrete?

10. In an ordinary structure what percentage change in length can be expected in concrete during hardening?

11. If the amount of steel in an unloaded reinforced concrete member is greater than 1.5%, what stress may be produced in the concrete if it becomes thoroughly dry?

UNIVERSITY OF CALIFORNIA EXTENSION DIVISION
Correspondence Courses

Materials of Engineering Construction

Civil Engr.-8B Assignment 17. Professor C. T.Wiskocil

PERMEABILITY AND ABSORPTION OF CONCRETE

Read Articles 523 to 532 inclusive. Impermeable concrete is required in the construction of basements, tunnels, and subways, and of tanks for the storage of liquids. Waterproof is the term more commonly used to designate concrete which prevents the passage of water through it. Leaks not only defeat the purpose for which impermeable concrete is intended but permit the entrance of sea water, alkalies, and frost, all of which affect the durability of concrete. If concrete is properly proportioned, mixed, placed and cured, it is possible to secure a finished product that will be impermeable under water pressure up to and exceeding that produced by a 100 foot head. If the structure is liable to crack, water-tight expansion joints must be provided or the use of waterproof membranes, as described in Article 538, must be resorted to.

Read Article 523, which explains the difference between absorption and permeability. Note that the statement is made that there is no relation between these properties. Both are important. Absorption is easily determined but permeability can be determined only by the use of an elaborate arrangement to test the specimen, and even this does not always work satisfactorily.

Read Article 524. The principal types of permeability specimens are illustrated on page 483. The main cause of trouble in tests of this kind is leaks particularly at high pressures. While several

types of specimens are illustrated there is no accepted standard and moreover this test is not frequently made.

With increasing proportions of cement, other variables remaining constant, the impermeability of concrete increases. See Article 525.

Figure 16 on page 486 and figure 9 on page 464 show that the density of concrete affects its permeability more than it does the strength. A porous concrete might have considerable strength and yet be very permeable to water.

The use of insufficient mixing water makes the placing of concrete difficult and usually results in a pouous product. An excessive amount of water produces a large amount of water-voids and decreases the density. The most impervious concrete is made from a plastic, workable mix. See Article 527.

The one-minute mix, recommended by the Joint Committee previously referred to, is undoubtedly sufficient to insure homogeneity of mix and will therefore produce impermeable concrete, providing that the aggregates are well graded and the correct amount of cement and mixing water are used. With these latter conditions properly provided, insufficient mixing will cause permeability; but it is obvious that two or more minutes of mixing will not be able to overcome deficiencies in mix, grading of aggregates, or amount of water used, and will not under these conditions produce an impermeable concrete. Read Article 528.

Permeability as well as strength of concrete are greatly affected by improper curing. Inherent impermeability is destroyed by allowing concrete to dry out at early ages. Concrete must be kept damp in order to cure properly. See Article 489.

Minor factors which influence the permeability of concrete are given in Article 530. They are relatively unimportant.

The degree of absorption holds a prominent place in all specifications for quality of concrete products. Notwithstanding its importance it has not been thoroughly investigated. Read Article 531.

The A.S. T.M.Standards for testing cement-concrete sewer pipe for absorption state that the test specimen, a piece of broken pipe, shall be heated for not less than 3 hours at a temperature of not less than 110 degrees Centigrade (230° Fahrenheit). The specimen is than cooled, weighed and placed in water which is brought to the boiling point and boiled for five hours. After the water has cooled to room temperature the specimen is removed and the superficial moisture wiped off. The specimen is then weighed and the percentage absorption calculated on the basis of the dry weight.

As indicated in the first paragraph of Article 531, the excessive drying of the specimen undoubtedly increases the absorption.

In a recent report issued by the Structural Materials Research Laboratory, Lewis Institute, Chicago, the absorption of concrete was studied. While it was not determined in accordance with the A.S.T.M. specifications, various factors which influence absorption

were studied and the results should be of value. The following are the principal conclusions:

1. The absorption of concrete was reduced by using coarser aggregates, so long as the concrete was plastic. The absorption of concrete made with aggregate graded 0 -28 (fineness modulus of 1.8) was about 5%, while for concrete with aggregate graded 0 -1 1/2 inch (fineness modulus 6.0) the absorption was reduced to 2%.

2. The absorption of concrete was reduced by increasing the quantity of cement.

3. The absorption was increased as more mixing water was used.

4. The storage of concrete in a moist place immediately after molding decreased the absorption. The longer the concrete was kept moist the lower the absorption.

5. In general, in concrete of high strength there was low absorption.

WATERPROOFING

Read Articles 532 to 538 inclusive. In many cases concrete is poorly proportioned, mixed, placed and cured, and in such instances it is necessary to close up the pores in order to make the concrete impermeable. In most instances it would be cheaper to make good concrete than to resort to the use of waterproofing materials.

The principal method of filling the pores is by the addition of inert and active fillers. They are listed in Article 532. Some are added to the mixing water while others are dry powders and are added to the cement.

The statements made in Article 533 on the effect of hydrate lime should be seriously questioned. According to EFFECT OF HYDRATED LIME AND OTHER POWDERED ADMIXTURES IN CONCRETE by Duff Abrams, Bulletin 8 of the Structural Materials Research Laboratory, Lewis Institute, Chicago (Dec. 1920): (a) Hydrated lime as an admixture reduces the compressive strength of concrete of all mixes and consistencies. (b) The reduction of concrete strength is nearly proportional to the quantity of hydrated lime used. (c) Rich concrete mixtures show a greater loss in strength due to hydrated lime than lean ones.

If shrinkage cracks occur or construction joints are not well made the integral fillers will not keep out the water. Surface treatments are resorted to. In general they are not very successful. Sylvester's wash of soap and alum is described in Article 537. Other treatments are hot paraffin, bituminous materials and rich mortar.

The most positive method of waterproofing, but the most expensive, is the use of layers of waterproof membranes laid on the surface of the concrete subjected to water pressure. Tarred felt, burlap and canvas are some of the membranes used. They are cemented to the concrete with various bituminous materials. See Article 538.

EFFECTS OF TEMPERATURE ON CONCRETE

The effect of low temperature on fresh concrete is explained in Articles 539 to 542 inclusive. It is a well known fact that heat hastens the setting and hardening of concrete and that cold

delays it. Low temperature produces an appreciable effect below 50 degrees Fahrenheit and becomes more effective in retarding the phenomena of setting and hardening as it decreases, until the freezing point of water is reached. Below this temperature, fresh concrete will freeze.

When water is added to portland cement a chemical reaction occurs which evolves heat of sufficient quantity to raise the temperature of fresh concrete. Under favorable conditions the rise in temperature is greatest in the period from 6 to 12 hours after mixing.

If concrete is to be subjected to low temperatures it is important that it acquire all possible strength at an early age.

It is the general opinion that freezing temperature will not injure concrete that has had an opportunity to harden at least 48 hours under favorable conditions. Alternate freezing and thawing at an early age may cause injury.

Concrete should be protected from the elements for at least 12 hours after being poured during which time the heat from the chemical action accelerates hardening and retards the later cooling.

Light structures with thin sections need more protection than concrete poured in large masses. Furthermore, since the circulation of air has a marked effect on the cooling of heated bodies; fresh concrete should be protected from wind.

The diffusivity of fresh concrete of the usual mixes is .0063 in c.g.s. units. This constant expreesses the rate of flow of temperature. It is a function of the density, specific heat and

thermal conductivity. The emissivity of fresh concrete is the rate of loss of heat by radiation, convection, and evaporation of surface water. In c.g.s. units its average value is .046. These values have been determined by Tokujiro Yoshida, who has also prepared various cooling diagrams, thus affording data which permit calculations of the time required for concrete to reach freezing or any other given temperature under known conditions of initial temperature,mass and atmospheric temperature of the concrete, and the amount of protection given it after it is poured.

Heating of materials, which is an excellent method of ensuring early hardening and delaying the fall in temperature, should not be carried above 100 to 120 degrees Fahrenheit.

If the temperature of the concrete over a given period is known, the comparative strength may be estimated from Figure 15 in INFLUENCE OF TEMPERATURE ON THE STRENGTH OF CONCRETE by A.B. McDaniel, Bulletin 81, of the Engineering Experiment Station, University of Illinois. This is an aid in deciding on the safe time to remove forms when the temperature is low.

The three methods of concreting in cold weather are: heating the materials, placing protective coverings over the poured concrete, and the use of chemicals to lower the freezing point. Calcium chloride, see Article 542, is being used to accelerate the setting of concrete at low temperature, even on large and important work. Part of the 410,000 cu. yds. of concrete on Ontario's Niagra Power Development, according to an article by Blanchard and Young,

in the Engineering News-Record of April 6, 1922, page 554, was poured in freezing weather. Two and one half percent of calcium chloride was used and due to the acceleration it caused in the hardening, the forms were stripped in 12 hours. It is interesting to note that all this concrete was scientifically proportioned to meet a definite strength requirement at 28 days.

Actual practice and laboratory experiments have demonstrated the value of calcium chloride in highway construction to such an extent that the Highway Department of the state of Illinois, during the past year (1921) has allowed its use for accelerating the setting of concrete in cold weather construction. They also have spread it over the usual concrete pavement to accelerate the setting under normal conditions. It was applied 8 to 16 hours after the concrete had been poured. About 3 lb. were used per square yard of surface. Experiments have proved that the hardening effect occurs during the first 24 hours the salt is on the concrete.

Calcium oxychloride, known as Cal, is readily soluble in water, in which it decomposes into calcium hydroxide and calcium chloride. It is a dry white powder and is not hygroscopic,like commercial calcium chloride. Portland cement mortars treated with Cal and stored in air, attained at 2 days a strength greater than that of untreated mortars at 28 days. Three-year tests by the Bureau of Standards on concrete gaged with a solution of calcium chloride are sufficient grounds for believing that the addition of Cal will not injuriously affect the ultimate strength and durability

of portland cement concrete.

The effect of high temperatures on concrete.- Read Article 543. While concrete is a good fire resistant material, ranking with burnt clay products such as brick and terra cotta, it will actually fuse and be destroyed when exposed to high temperatures. The temperature at which average concrete will fuse is about 2,200 degrees Fahrenheit. It probably varies slightly with the brand of cement and the type of aggregates used. Fused concrete has been found in ruins of hot fires such as those of the Edison plant, the chemical plant of the Barrett Manufacturing Co., in 1920, and the Seamless Rubber Company's plant in 1921, in which highly inflammable liquids caused the high temperatures. Such temperatures are generally not encountered but they are possible even in ordinary structures. In the fire in the office building of the Chicago, Burlington and Quincy Railroad Co. in Chicago, March 1922, temperatures in excess of 2,000 degrees Fahrenheit were reached. These temperatures were undoubtedly confined to relatively small areas. It is interesting to note that while the contents of the building within these areas were completely destroyed, the concrete adequately protected the steel frame of the building. There was a certain amount of spalling.

About 2 1/2 inches of concrete is generally considered sufficient thickness of fireproofing for steel work. Reinforced concrete columns should have 2 inches, while floor slabs are adequately protected with 1 inch of concrete.

It has been observed that concrete made with silicious aggregates is not as resistant to fire as concrete made with limestone, trap rock, and burnt clay aggregates. The distinct advantage in the use of concrete to fireproof steel is that its expansion and contraction are nearly the same as those of steel (see Article 544), and the spalling action(under heating and cooling) is therefore, reduced to a minimum.

Other thermal properties given in Article 545 are relatively unimportant. Recent tests by Carman and Nelson give .0037 as the average thermal conductivity for average concrete; see Table 26 on page 503 in the text.

DURABILITY OF CONCRETE

Read Articles 546 to 550 inclusive. The reliability of existing information on the disintegration of concrete by alkali is questionable. This statement does not apply to that given in publications listed at the end of Article 547 in the text, since these contain without question the most important contributions on the subject at the present time. Other investigations have been made but, taken as a whole, the results of these investigations and tests are not conclusive.

The most important examples of failure of concrete which have been reported are in Canada. The articles announcing these failures describe only the extent of disintegration and attribute the cause to alkali because of its presence in the surrounding soil. In no instance do they give the history of the concrete, which may have

been a lean mixture, or made of poorly graded aggregates, or sand with organic matter in it; or which again, may have been poorly mixed or made with an excess amount of water. Any of these conditions would yield a concrete of low durability or resistance to weathering. The Winnipeg aQueduct is probably the most important structure which shows disintegration but there are many other concrete structures which are satisfactorily withstanding forces similar to these which seem to be disintegrating this structure. The subject is important and is at present being thoroughly investigated by the Portland Cement Association with other engineering societies and interested engineers.

Structures of concrete and reinforced concrete have shown partial disintegration under the action of sea water, frost, and stray electric currents, as well as alkali. They have usually been made of porous concrete or are of such shape that they crack under the action of the loads which come upon them, so that the water entering the concrete can exert its disintegrating influence. Well made concrete that has been properly cured has not been affected by these disintegrating agencies. The materials and methods to be used in order to secure good concrete have been discussed in previous assignments.

Portland cement products.- Read Articles 551 to 561 inclusive. Concrete blocks were probably the first product in the pre-cast concrete industry. As a whole they were poorly made and fashioned after an imitation of rock-faced stone. The inferior quality of the

product, which was a poor imitation of cut stone, caused the early failure of the industry. At the present time, however, architectural concrete stone is successfully competing with natural stone for the facing and trimming of buildings. Important examples of such construction are found on the campus of the University of California at Berkeley, in the case of Hilgard Hall and Gilman Hall. The color combinations in Hilgard Hall are particularly pleasing. The color designs were executed in what is known as scraffito. Pre-cast trim and scraffito offer a permanent material that is relatively inexpensive (when compared with natural stone) and will undoubtedly be used in the construction of other buildings on the campus. Most pre-cast trim is made by the dry cast method in which specially prepared molds are used. The product is immediately removed from the molds, pointed-up where defective in surface finish, and set aside to cure. Considerable care must be taken in curing these products. Concrete stone is also made by pressure and wet cast methods. The American Concrete Institute has given the name concrete architectural stone to this product.

Was used in construction of Student Union and Le Conte Hall, 1922.

Concrete pipe is another important pre-cast product. The cost of manufacture depends largely upon the method of manufacture. Under present methods of manufacture a very satisfactory product is being made. The principal difficulty in the use of pre-cast concrete pipe for pressure purposes is the joint.

QUESTIONS.

1. Define impermeability. What is its relation to absorption as applied to concrete?

2. What are the two methods used to determine permeability of concrete?

3. What are the principal causes for permeable concrete?

4. What are the principal causes for high absorption in concrete?

5. What is the most effective method of waterproofing concrete?

6. What factors affect the length of time it takes fresh concrete to cool in freezing weather?

7. What is the minimum time that fresh concrete should be kept at a temperature favorable to hardening?

8. What is the temperature at which concrete will fuse?

9. Are temperatures necessary to fuse concrete ever reached when buildings are destroyed by fire?

10. What are some of the causes of the disintegration of concrete?

11. Discuss the effect of sea water on the durability of concrete.

12. What are the principal portland cement products?

13. How are pre-cast concrete products cured?

UNIVERSITY OF CALIFORNIA EXTENSION DIVISION

Correspondence Courses

Materials of Engineering Construction

Civil Engr-8B. Professor C.T. Wiskocil

Assignment 18.

METALS AND THEIR ORES

Read Articles 562 to 568 inclusive. This chapter is an introduction to the study of metals which is now to be taken up. That part of Article 564 which describes certain metals may be omitted at this time because it must be reviewed later in the course when these metals are discussed in detail.

Since this chapter is introductory it is relatively unimportant. The essential parts will be discussed later.

Article 563 lists the important base metals used in engineering construction. They are iron, copper, lead, and zinc. Aluminum is an important metal of secondary rank. Iron and aluminum, in the list given below, are small in percentage, but are found in abundant quantities.

Average composition of earth's crust

Oxygen	47.05	Phosphorus	0.11
Silicon	28.26	Sulphur	.11
Aluminum	7.98	Florine	.10
Iron	4.47	Barium	.097
Calcium	3.43	Manganese	.077
Magnesium	2.34	Chlorine	.06
Potassium	2.50	Chromium	.033
Sodium	2.54	Strontium	.033
Titanium	0.45	Zirconium	.025
Hydrogen	0.16	Nickel	.023
Carbon	0.13	Vanadium	.018

Read carefully the first paragraph of Article 564.

An ore may be said to be a mineral or a mixture of minerals from which one or more elements may be extracted with profit. As indicated in Article 565 it is seldom that a deposit consisting of but a single mineral is encountered.

Read carefully the article on the principles of extraction of metals, Article 568. This brief outline of principles will be useful when the methods are studied in detail.

REDUCTION OF IRON FROM ITS ORES

Iron Ores and Ore Deposits:- The reading assignment covers Articles 569 to 573 inclusive.

Read Article 569 on the economic importance of iron and steel and review the paragraph on iron in article 564, previously referred to. Iron is sometimes referred to as the master metal. No other one metal has contributed so much to our welfare and comfort. There is scarcely an article we use that is not produced from iron or by means of it. There is no exact substitute for it, The automobile and the railroad could not have been developed without it.

The native sources of iron ores that are being exploited at the present time are listed in Article 570. As the United States becomes more densely populated the deposits in the western states, such as those now known to exist in Colorado, Utah, New Mexico, Idaho and Montana, will be developed.

The Lake Superior district is the most important ore region

in the United States. It is made up of isolated bodies of ore surrounding Lake Superior. These ore bodies or ranges are scattered over Michigan, Wisconsin, Minnesota and Ontario (in Canada). The Marquette range is in Michigan, along the shore of Lake Superior. It was discovered in 1844 and operation was begun in 1854. The ore is principally red hematite, and small amounts of magnetite and limonite. The Menominee range, also in Michigan, was opened in 1872. It is composed mainly of hematite. The Gogebic range is partly in Michigan and partly in Wisconsin. It was opened in 1884. The ores are mostly dehydrated hematites which are red in color and rather soft. The Vermillion range, which lies in Minnesota, was opened the same year as the Gogebic range. The ores are hard hematites of red and blue color. These ranges constitute the oldest group. The latest ranges opened, the Missabe in 1892 and Cuyana in 1911, are the most important. The greater part of the ore used in the production of pig iron today comes from the Missabe range. It lies in Minnesota, and yields soft hydrated hematites and limonites. The deposits are comparatively shallow. The Cuyana range also lies in Minnesota. Many of the ores in this range contain manganese and are mined for their manganese content only. Some have as much as 45% of manganese. Both underground and open-pit mining is carried on in the Superior District. Most of the mining on the Missabe range is done with steam shovels.

The Birmingham District is second in importance of the Lake Superior district. It is in Alabama. The ore is a variety of red

hematite and occurs with shale, sandstone and some limestone. Most of the mines now being operated are worked by underground methods On account of the proximity of ore, limestone, and coal suitable for making coke, this district has an advantage over other districts in the country. The ore usually contains about .8% phosphorus. The duplex or triplex process is employed and a slag with a high phosphorus content is obtained when the pig iron is purified. This slag is used as a fertilizer.

Grouped according to chemical composition the chief iron bearing minerals are the iron oxides, iron carbonates, iron silicates and iron sulphides. Only the oxides are a factor in the manufacture of steel in the United States.

In Article 571 the iron ores are considered in order of their iron content.

Magnetite is ferro-ferric oxide. It is found in Arkansas and New Jersey, as well as in the states named in Article 571. Its magnetic property is made use of in the location of ore bodies below the surface of the ground and in mechanically purifying the the ores, by magnetic concentration.

Hematite is anhydrous ferric oxide, Fe_2O_3. It furnishes the base of the world's most important ores. Hematite ores are widely distributed and vary in iron content; the principal ones are red hematite, specular hematite, oölitic hematite and fossil ore.

Limonite is a hydrous ferric oxide. The group of ores from turgite to limonite varies in iron content from 66 to 52%. The formula for limonite and its iron content is given in the text.

These minerals are widely distributed throughout the United States. In Virginia they make up the greater part of the available ores.

Siderite, a ferrous carbonate, is the principal ore in the carbonate group. It is sometimes called kidney ore, spathic iron ore, or blackband. It is not a commercial ore in the United States but is important in England. The ores of the above divisions are usually calcined before they are charged into the blast furnace.

The manufacture of pig iron:- Reading assignment, Articles 574 to 584 inclusive.

While the purpose of this part of the assignment is to describe the manufacture of pig iron, a few remarks on the history of iron would be of interest at this point. The date of the first use of iron is not known. Archaeological research has determined that it has been in use through a period of only about 4,000 years. Since iron corrodes and therefore leaves no trace, it is difficult to find evidence of its early use. Doubtful evidence exists to show its use in the construction of the pyramids about 4000 B.C., but its use by the Assyrians about 1500 B.C. and later by the Greeks is more certain. The Romans became quite proficient in the use of metallurgy, as is shown by their weapons. The Britons had some knowledge of iron before the Roman occupation of England under Caesar. At that time iron was probably produced by heating ore and charcoal in a flat bottomed forge until a small body of pasty metal was obtained which could be hammered and worked into wrought iron. A process similar to this was used in Europe until about 1350. At

this time there was first used a crude blast furnace in which was produced an iron that could be cast. The blast furnace method was improved in England in 1619 by the use of coke instead of charcoal as the fuel. About 200 years later the hot blast was introduced. The first American iron works was operated in Virginia in 1619 and the first blast furnace was built about 100 years later. The most important advances in blast furnace construction and operation began to be made about 1880.

The reduction of iron ore to pig iron is brought about by charging alternate layers of ore, fuel, and flux in proper proportions through a specially designed opening into the top of a blast furnace (a tall vertical stack, lined with fire brick), while hot air is blown into the bottom of the furnace. The nitrogen and the products of combustion pass upward through the furnace and escape at the top. At periodic intervals impurities, in the form of slag, are drawn off near the bottom and molten metal is removed through a tap-hole in the hearth. In early furnaces the metal was cast in sand molds which were arranged in rows and resembled a litter of pigs; hence the metal was called pig iron.

The operation of a blast furnace is continuous, one charge following another without a break. Since iron ore is generally an oxide it must be deoxidized or reduced in order to obtain metallic iron. Carbon is the reducing agent and, in the form of coke, it is used as fuel. During the reducing process the iron absorbs carbon so that pig iron has a high carbon content.

Coke is the principal fuel used in the manufacture of pig iron. Anthracite coal and charcoal are used to a limited extent. Coke is the residue of the destructive distillation of bituminous coal. For blast furnace use it must be porous, so as to be readily burned, and strong so as to withstand the load of the ore and other materials above it without crushing. The by-product or retort process for making coke is rapidly replacing the bee-hive process. In the latter process air is admitted into the coking chamber and the products of distillation are burned and thus wasted. In the by-product process the coking chamber is air tight and heat is supplied to the outside to coke the coal. The products of distillation are recovered. These products are hydrocarbon gases, tar and ammonia. The method of manufacture has little effect on the quality of the coke.

Smelting is a metallurgical operation in which metal, in a state of fusion, is separated from impurities with which it is combined. It involves two processes, one, the reduction of the metal, and the other, the separation of the metal from the mixture. These operations are facilitated by the use of a flux. The primary function of the flux is to render the materials more readily fusible and the secondary function is to supply a substance with which the elements originally combined with the metal may combine. The flux should be free from impurities such as sulphur and phosphorus. The materials to be fluxed determine the character of the flux. If they are basic, an acid flux must be used. In most ores, however, the impurities are acid so that the predomina-

ting flux is basic. Basic fluxes are limestone and dolomite. In the smelting zone of the blast furnace the flux combines with the gangue to form slag. Slags furnish the means by which impurities are separated from the metal and removed from the furnace. In the blast furnace the slag, on account of its fusibility and dissolving power, forms the only positive method of removing sulphur. Slag has a low density and floats upon the metal. It protects the metal from the hot gases and prevents overheating and at the same time conserves the heat in the metal. Since it has the power of dissolving oxides it keeps the metal clean and also facilitates the separation of impurities from the molten metal.

The modern blast furnace and its accessories are illustrated in Figure 1 on page 534. Be able to sketch the cross section of a blast furnace. Be sure to show the double bell-hopper at the top.

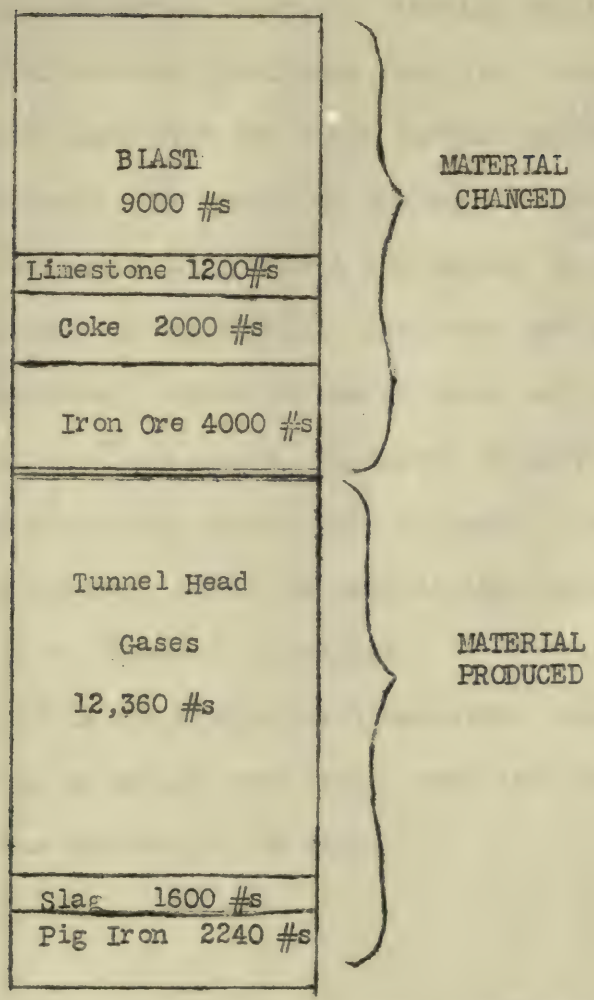
The best practice today in blast furnace construction is represented by furnaces from 90 to 100 ft. high (see the information at the bottom of page 533 in the text). In these furnaces, the hearth or crucible is about 10 ft high. The bosh zone is from 10 to 12 ft. high, and the stack 70 ft. or more.

Be able to describe the operation of the hot stoves. The air is heated to about 1000 degrees Fahrenheit in the stoves and forced into the furnace through tuyeres (pronounced twē´ yâr´) at about 15 lb. per sq. in. pressure. The temperature in the blast furnace varies from a maximum of about 3500 degrees F. at a point just above the tuyeres to about 500 degrees F. at the stack line,

at the top of the furnace. The efficiency of the furnace is greatly increased by the use of preheated air.

The greatest single improvement in blast furnace operation since Neilson's hot blast is James Gayley's dry blast process. It has been estimated that in the summer months a furnace which uses 40,000 cu. ft. of air per minute will take in with this amount of air about 225 gal. of water per hour. It is obvious that this water will reduce the efficiency of the furnace. In Gayley's process, the moisture is removed from the air by drawing it over a system of pipes cooled with brine which in turn is cooled with liquified ammonia. The moisture is condensed and frozen on the pipes, leaving the air practically dry. This is a refrigeration process. The dry air is forced through the hot stoves and then into the furnace. In spite of the advantage of the dry blast it is still most common practice to use undried air. It is probable, however, that the dry blast will soon become as universally used as Neilson's hot blast.

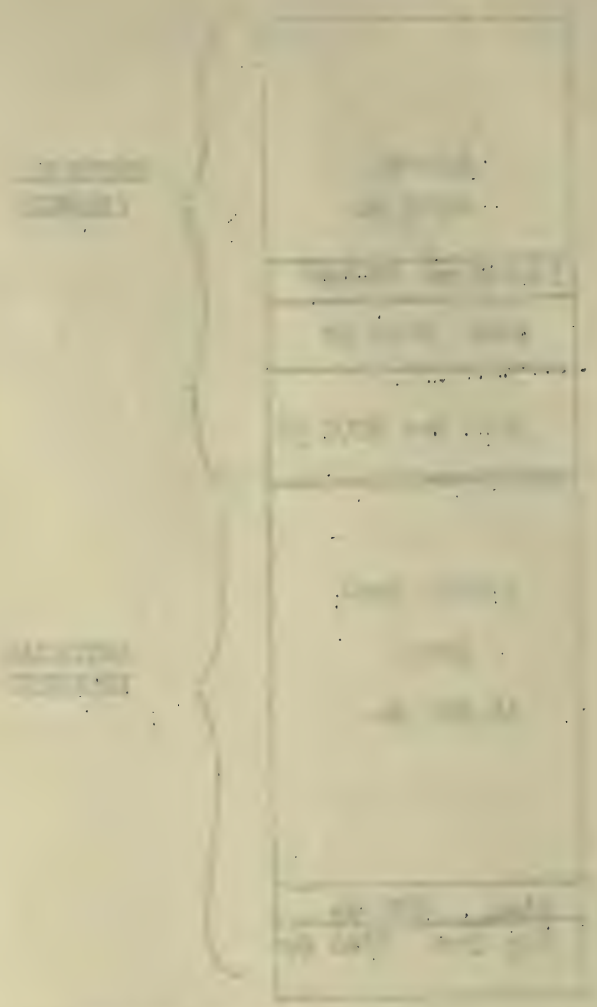
The amount of materials used by a modern blast furnace in 24 hours is very impressive. These are given in the last paragraph of Article 578 on page 535. It is evident that even a single unit plant means a large production which necessitates large working capital.



Amounts of material charged and produced in making one ton of pig iron.

This represents American blast furnace practice in the northern district.

If pig iron is to be used in the production of steel it is transferred to the converters or steel furnaces in the molten condition if they are near by. When the blast furnace is not part of the steel plant it is necessary to cast the metal into pigs and transport it in that condition. The old method was to use sand molds, from the arrangement of which, as has been stated, pig iron



got its name. The present method is to use casting machines. These are an endless chain of buckets lined with fire clay which receive the molten metal as it comes from the blast furnace and dump the solidified pigs into cars. The length of the bucket line is such that the iron has time to solidify before the bucket is dumped.

Blast furnace slag is run off into slag cars and dumped on the waste pile or granulated with a stream of water and used later in the manufacture of portland cement. A stream of water is more effective than dumping the slag into a body of water. Some slag is used for ballast for railway tracks and some in the manufacture of mineral wool; most of it, however, is wasted.

Pig iron itself is not a structural material. When remelted and cast into molds it is called cast iron. Cast iron forms the basic material for the manufacture of steel.

QUESTIONS

1. Where are the principal iron ore deposits in the United States?
2. What are the principal iron ores? Give the mineralogical name and the approximate iron content in tabular form.
3. Outline the process of manufacture of pig iron.
4. What is pig iron? Why is it called pig iron?
5. What is a flux? Why is a flux used in the manufacture of pig iron?
6. Of what use is slag in the process of smelting?
7. Sketch the cross section of a blast furnace, give the approximate dimensions and name the essential parts.
8. What are the two recent improvements in blast furnace operation which have greatly increased its efficiency?
9. How much raw material is charged into a blast furnace to produce a ton of pig iron?
10. What are the principal changes involved in the production of pig iron from the iron ore?
11. What are the requirements for blast furnace coke?

UNIVERSITY OF CALIFORNIA EXTENSION DIVISION

Correspondence Courses

Materials of Engineering Construction

Civil Engr-8 B. Professor C.T. Wiskocil

Assignment 19.

THE MANUFACTURE OF WROUGHT IRON

Introduction:- Read Articles 585 and 586. In the blast furnace operation the metal absorbs large amounts of carbon which, together with other impurities, render it too brittle and coarse for structural use. All the methods used to refine pig iron are essentially processes for the removal of the carbon by means of oxidation. As shown in Article 586, carbon is the only impurity that is removed in the form of a gas. Other impurities are taken up by the slag and separated from the metal in that way.

Before large-scale production of steel was possible, wrought iron was the most important metallic structural material. It was rolled into various shapes, which were used in the construction of buildings, ships, bridges and structures of all kinds. It had sufficient strength besides ~~its~~ toughness and ductility. Furthermore it was easily forged. These properties made it more adaptable than cast iron. It was used for tools and implements that did not require a tempered edge. The development of the Bessemer and open-hearth processes for making steel occurred in the latter part of the nineteenth century; since that time steel has replaced wrought iron as the principal structural material. Wrought iron is still extensively used for general blacksmith work, and for water and

gas pipes, because of the belief that it resists corrosion better than steel. It is also used for rods and bolts which are to be subjected to impact or shock because of the belief that this material, with its fibrous structure, is more resistant to shock than steel. Wrought iron has failed to compete successfully with soft steel chiefly on account of the high cost of labor. The process of manufacture is most laborious and yet requires considerable skill. The skill gained by experience in the process is superior to a theoretrical knowledge of it. These conditions make it difficult to obtain men since the intelligence required could obtain higher rewards in other pursuits.

The International Association for Testing Materials defines wrought iron as "malleable iron which is aggregated from pasty particles without subsequent fusion, and containing so little carbon that it does not harden usefully when cooled suddenly." Bradley Stoughton's definition is, "Wrought iron is almost the same as the very low-carbon steel except that it is never produced by melting and casting in a mold but is always forged to the desired size and form. It usually contains less than 0.12% of carbon. Its chief distinction from the low-carbon steels is that it is made by a process which finishes it in a pasty, instead of a liquid form and leaves about 1 to 2 % of slag mechanically disseminated through it."

The puddling process:- Read Article 588. In the manufacture of wrought iron, a special grade of pig iron known as forge pig is used. It is high in silicon. The silicon is desirable since

it aids in the formation of sufficient slag to cover the bath and prevent excessive oxidation of the iron. Phosphorous and sulphur must be kept low since they are not completely removed with the slag.

Basic iron oxides are used to fettle the hearth. Iron ore is frequently used to line or fettle the furnace. The position of the fettling material is shown in Figure 1 on page 544. During the boiling stage the carbon unites with the oxygen supplied mostly by the fettling material and later by the air passing over the bath. The slag must be strongly basic at this stage so that it will retain the phosphorous and sulphur.

Slag is never completely removed in the squeezing process. It is always present in wrought iron in the form of fibers which extend in the direction of rolling. This is the distinguishing characteristic of wrought iron. It can be detected by etching a polished surface with acid. Under the microscope the structure is clearly revealed, as shown in Figure 1 on page 598. The nick-bend test is also used to identify wrought iron. The piece of metal is cut partly through and then bent. The fibrous structure will be shown by this test.

The classes of wrought iron are given in Article 589. Charcoal irons are the purest grades of wrought irons. They are used in the manufacture of electrical apparatus and boiler tubes, as well as for those purposes listed in Article 589. Wrought iron costs more than low-carbon steel. It is, therefore, sometimes adulterated with steel scrap. The scrap and the wrought iron are

piled together and brought to a welding temperature and rolled into merchant bars. The product is sold as wrought iron. This material should not be confused with the charcoal or knobbled iron described in the text. Read Article 589.

THE MANUFACTURE OF STEEL

Introduction:- Read Article 590. It is not possible to give a concise definition of steel. Probably the most satisfactory one is that given by H.M. Howe. "Steel is that form of iron which is malleable at least in some one range of temperature, and in addition is either (a) cast into an initially malleable mass; or (b) is capable of hardening greatly by sudden cooling; or (c) is both so cast and so capable of hardening." Cast iron and pig iron are not malleable but chrome and manganese steels are malleable only through a short range of high temperatures; at ordinary temperatures they are not malleable. The condition in (a) distinguishes steel from malleable cast iron, which is made malleable by special treatment after it is cast. Wrought iron is not cast and it cannot be hardened by sudden cooling. Cementation steel (see page 556) is not cast, but it will harden upon sudden cooling; there are also many carbon steels which are cast but will not harden. These facts will show why it is difficult to define steel.

Iron oxide and air are available for the purification of pig iron. The oxide of iron is the principal substance used in the manufacture of wrought iron. Iron ore and air are the oxidizing substances used in the manufacture of steel but they require different

The following is a sampling distribution that might be encountered in the real world. Each problem is independent of the others.

1) Each of the following statements is either true or false. Indicate which is which.

a) The mean of the sampling distribution of the sample means is always equal to the mean of the population from which the samples were drawn.

b) The standard deviation of the sampling distribution of the sample means is always smaller than the standard deviation of the population from which the samples were drawn.

c) The sampling distribution of the sample means is always normal.

d) The sampling distribution of the sample means is normal if the population from which the samples were drawn is normal.

e) The sampling distribution of the sample means is normal if the number of samples is large.

f) The sampling distribution of the sample means is normal if the number of samples is large and the population from which the samples were drawn is normal.

g) The sampling distribution of the sample means is normal if the number of samples is large and the population from which the samples were drawn is not normal.

h) The sampling distribution of the sample means is normal if the number of samples is small and the population from which the samples were drawn is normal.

i) The sampling distribution of the sample means is normal if the number of samples is small and the population from which the samples were drawn is not normal.

j) The sampling distribution of the sample means is normal if the number of samples is large and the population from which the samples were drawn is not normal.

k) The sampling distribution of the sample means is normal if the number of samples is small and the population from which the samples were drawn is normal.

l) The sampling distribution of the sample means is normal if the number of samples is small and the population from which the samples were drawn is not normal.

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n) The sampling distribution of the sample means is normal if the number of samples is small and the population from which the samples were drawn is normal.

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p) The sampling distribution of the sample means is normal if the number of samples is large and the population from which the samples were drawn is not normal.

q) The sampling distribution of the sample means is normal if the number of samples is small and the population from which the samples were drawn is normal.

r) The sampling distribution of the sample means is normal if the number of samples is small and the population from which the samples were drawn is not normal.

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z) The sampling distribution of the sample means is normal if the number of samples is small and the population from which the samples were drawn is normal.

aa) The sampling distribution of the sample means is normal if the number of samples is small and the population from which the samples were drawn is not normal.

bb) The sampling distribution of the sample means is normal if the number of samples is large and the population from which the samples were drawn is not normal.

cc) The sampling distribution of the sample means is normal if the number of samples is small and the population from which the samples were drawn is normal.

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ee) The sampling distribution of the sample means is normal if the number of samples is large and the population from which the samples were drawn is not normal.

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hh) The sampling distribution of the sample means is normal if the number of samples is large and the population from which the samples were drawn is not normal.

ii) The sampling distribution of the sample means is normal if the number of samples is small and the population from which the samples were drawn is normal.

jj) The sampling distribution of the sample means is normal if the number of samples is small and the population from which the samples were drawn is not normal.

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yy) The sampling distribution of the sample means is normal if the number of samples is small and the population from which the samples were drawn is not normal.

zz) The sampling distribution of the sample means is normal if the number of samples is large and the population from which the samples were drawn is not normal.

kinds of apparatus. The two chief methods of purification are the pneumatic and the open hearth. In both methods the purification may be accomplished by oxidation alone, in which case they are called acid processes. If oxidation is carried on in the presence of strong bases the process is known as the basic process. In the acid process, only carbon, silicon, and manganese are removed from the iron. In the basic process, in addition to these elements, the phosphorus is also removed. The pig iron produced in this country is best adapted to treatment by the basic open hearth and the acid Bessemer process. These are the leading methods used in the manufacture of steel.

The Bessemer process of making steel:- Read Articles 591 to 595 inclusive. This process consists essentially in blowing air under a pressure of 20 lb. per sq. in. through a bath of molten iron contained in a specially constructed vessel known as a converter. The silicon and manganese combine with oxygen and form a slag while the carbon forms Co and CO_2 and passes out of the bath. The heat required to maintain the temperature of the bath is obtained from the chemical action which occurs when the elements are oxidized. Steel made in this way contains oxides which render it unfit for use. A recarburizer must, therefore, be added after the metal is blown to give it the necessary strength and toughness. The process is explained in detail in Article 593; study this article carefully.

The mixer described in Article 593 and illustrated in Figure 3, on page 548, is very important in the Bessemer process. Besides acting as a storage place for hot metal as indicated in the text

it conserves the heat in the molten metal and makes the charge taken to the converters more uniform. Mixers average in size from 200 to 1200 tons capacity.

Pig iron suitable for the manufacture of steel by the pneumatic process (acid) should contain 3 to 4% carbon, 1 to 1.5% silicon, less than 0.1% phosphorus, and small amounts of sulphur and manganese.

Basic Bessemer is successful only with pig iron which is high in phosphorus and low in silicon. There are practically no ores mined in the United States that are high enough in phosphorus for the basic Bessemer process. Pig iron with too much phosphorus for the acid Bessemer is made into steel by the basic open hearth process.

The Siemens process of making steel:- Read Articles 596 to 598 inclusive. The process is described in detail and is very important.

There are several distinct modifications of the basic open hearth process. There is the pig-and-ore process, the pig-and-scrap process and the all-scrap process. The pig-and-scrap process is now in most general use. When pig iron is expensive, as it is out here on the Pacific Coast on account of high transportation charges, the all-scrap process is most economical. The mills in the bay region, such as the Pacific Coast Steel Company at South San Francisco, the Judson Steel Company at Emeryville, and the Columbia Steel Company at Pittsburg, all use the all-scrap process.

The basic open hearth method is employed and a high grade of steel is produced. The nearest blast furnace is at Pueblo, Colorado.

Remember that the recarburization of basic steel cannot be accomplished in the furnace because the carbon, silicon and manganese in the recarburizer would reduce the phosphorus in the slag and restore it to the metal. For this reason the recarburizer is added to the metal in the ladle. Since the recarburizer cannot conveniently be molten, it must be ferro-manganese instead of the spiegeleisen which is used in the acid open hearth process.

Study Article 599. In it is a summary of the two most important processes for making steel.

Read Articles 600 and 601. A method by which the acid Bessemer and the basic open hearth processes are combined is described in the latter article. This process is known as the duplex process. It is used extensively in the south where the ore has a high phosphorus content.

Read Articles 602 to 604 inclusive on the minor methods of making steel.

The manufacture of blister steel or cementation steel is described in Article 602. This steel is very expensive but is of high quality. The cementation process has never been used to any great extent in the United States. The cementation process resembles the case hardening process used to give wrought iron and soft steel a hard surface of high-carbon steel. See Article 710 in the text.

The manufacture of crucible steel is described in Article 603. This method of making steel is widely used when a high grade product is wanted. Obviously crucible steel cannot be made in large quantities. This steel is superior to open hearth and pneumatic steel because it is made in closed vessels out of contact with the air. Crucible steel is less expensive than blister steel.

Electric steel:- Study Article 604. The Stassano furnace is of the radiation arc type. From an electrical standpoint this furnace has the important advantage of uniform power consumption. Only small sized Stassano furnaces have been built and are not in wide use.

The induction type of furnace was adapted to the manufacture of steel by Kjellin. It is impossible to obtain high temperatures in this type of furnace, hence it is not adapted for desulphurizing operations in which sulphur is removed as sulphide. The Heroult furnace of the arc resistance type heads the list of electric furnaces in use for the manufacture of steel.

The following information was taken from a paper by Keeney and Lyon, of the United States Bureau of Mines: "For many years all high grade steels were manufactured by the crucible process but since the advent of the electric furnace there has been a gradual adoption of that furnace for refining steel. For the complete refining of the higher grades of steel, the use of the electric furnace is now thoroughly established. Any products that can be

made by the crucible process can be made by the electric process, and in most cases with cheaper raw materials and at a low cost. In the electric furnace complex alloy steels can be made with precision. The high temperatures attainable facilitate the reactions, and alloys need not be used so largely for the purpose of removing gas. Very low carbon steel can be kept fluid at the high temperatures. Steel free from impurities and of great value for electrical apparatus can be made. With the electric furnace large castings can be made from one furnace, whereas in the crucible process steel from several crucibles must be used. For small castings, which require a very high grade metal free from slags and oxides, electrically refined steel is especially adapted. The electric furnace gives a metal of low or high carbon content as desired, hot enough to pour into thin molds, and steel free from slags and gases.

"Recent experiments show that electric processes have the following advantages over acid Bessemer and basic open hearth methods. A more complete removal of oxygen; the absence of oxides caused by the addition of silicon, manganese, etc.; the production of ingots of 8 tons and smaller that are practically free from segregation; the reduction of the sulphur content to .005% if desired; and the reduction of the phosphorus to .005%, but with the complete removal of the oxygen."

Considering the various methods of making steel, the process in which the electric furnace is used in connection with the basic

open hearth will yield the greatest amount of steel with highest efficiency and quality of product.

The assigned subject is thoroughly covered in the text, Chapter XVIII, and it should be carefully studied since it is very important. The following questions cover only a few of the important points. You should be able to answer similar questions on the other points in the chapter.

QUESTIONS

1. What is the importance of wrought iron as a structural material?
2. Define wrought iron.
3. Describe briefly the process by which wrought iron is made.
4. What is the source of the oxygen required to purify pig iron in the puddling process?
5. Why is it necessary to have a basic slag?
6. What tests are used to distinguish wrought iron from soft or or low-carbon steel?
7. Why is wrought iron sometimes adulterated with steel scrap?
8. What are the leading methods of making steel in the United States?
9. Describe briefly the pneumatic process.
10. What is a recarburizer and why is it used?
11. Why is the basic Bessemer process not used in the United States?
12. Sketch the cross section of a converter.
13. What are the principal chemical changes that take place during the open hearth process of making steel?
14. Why are different furnace linings used for the acid and basic processes?
15. When is the recarburizer added in the basic process and why?
16. Compare the pneumatic and the open hearth processes for making steel by tabulating the advantages and disadvantages.
17. Why is crucible steel more expensive than open hearth or Bessemer steel?
18. Why is it that a higher grade of steel can be obtained by the crucible process than by the Bessemer method?
19. What are the advantages of the electric furnace in the manufacture of steel?
20. Why does the electric furnace produce a higher grade of steel than the open hearth process?

UNIVERSITY OF CALIFORNIA EXTENSION DIVISION

Correspondence Courses

Materials of Engineering Construction

Civil Engr-8 B, Professor C.T. Wiskocil

Assignment 20.

THE MANUFACTURE OF IRON AND STEEL SHAPES

Study Article 605 to 616 inclusive.

Methods of shaping steel:- Read Article 605. The next step in the manufacture of steel, after the refinement of the cast iron, is to make it into the various shapes and forms required by the uses to which it is to be put. The shaping is a process either of casting or of mechanical working. Since steel is usually in a molten state after being refined, it would appear that casting would be the most economical method of shaping it. But metal cast from the molten state has an inherent lack of strength and ductility when compared with similar metal which has been mechanically worked into shape. Some shapes are so intricate in form that they must be cast and in others no great strength is required so that casting is a regular method employed for shaping many steel products. The chief causes of weakness in steel castings are blow holes, segregation, and crystallization. These defects can be minimized by proper methods of manufacture and the use of alloys is resorted to so that steel castings can be made of relatively high strength and quality of metal.

The mechanical working of steel can be carried out by three different methods; namely, hammering, pressing, and rolling. Hammering and pressing are frequently classed together as forging.

Steel is probably more widely used in rolled shapes than in any other form. Steel plate for tanks and boiler shells; structural shapes, such as I-beams, channels and angles; bolts, nuts, rivets, nails, rails, wire, chain; and tubing and pipes are some of the products made from rolled steel.

Steel ingots:- Read Article 606. Steel ingots for rolling or forging usually weigh from 3 to 10 tons. The average life of an ingot mold is about 100 heats.

During cooling, ingots naturally develop certain defects. The principal defects are mentioned in this article. They are pipes, blow holes, segregation, and crystallization. Other defects, such as checks, scabs, and slag inclusions, are incidental.

Pipes are caused during the solidification of the metal, as described in the text. The size of the pipe in Figure 2 on page 560 is rather larger than usual. Pipes are caused where the surface of the metal becomes oxidized so that it will not weld up in rolling; when this occurs the pipe appears as a defect even in the smallest section into which this part of the ingot may be rolled. Pipes are liable to cause accidents in rolling. The only way of dealing with the pipe is to crop the ingot and discard the part which includes the pipe. This method causes considerable waste and various schemes have, therefore, been devised to overcome the pipe without having to crop the ingot. The most promising is the hot-top mold. The idea is, to put it briefly, to keep the top of the mold molten and thus prevent the formation of the pipe. In the ordinary mold the top is the first to solidify.

To make the top the last to freeze the upper part of the ingot is made larger, and the upper part of the mold is made thinner. A different method, which has been used to a limited extent, is that in which the ingot is compressed while the interior is molten. This also tends to prevent the formation of the pipe.

Blow holes are another serious defect. The illustration (Figure 2, on page 560) is again slightly inaccurate. The surface cavities are very small, while the deep seated blow holes are frequently large. The latter may be over an inch in diameter. While the holes just beneath the skin of the ingot may be microscopic in size they are, nevertheless, the most troublesome. They are more liable to develop oxidized surfaces and thus to produce seams in the finished products. The deep seated holes are not subject to oxidation and since they tend to reduce the size of the pipe they are not harmful. The method of compressing the ingot, previously referred to, prevents the formation of large blow holes as well as pipes, but it is expensive. It is not widely used, because the cropping of the ingot is after all more economical. The metal discarded in cropping is used in the refining process as steel scrap. Steel that has been properly made and deoxidized at the time of recarburization will not have troublesome blow holes. Molten steel which is not properly deoxidized, and from which gas is bubbling, is known as wild steel. Aluminum is very effective in quieting or killing wild steel and it does not affect the properties of the steel. The killing is done in the ladle. Steel should be quiet before it is poured.

Electric steel, on account of its being refined without contact with air currents is particularly free from blow holes. Segregation is the localization of the impurities in the ingot. The ingredients in the molten metal have different freezing points. The substance with the lowest freezing point will be located near the top and center of the ingot, about at the bottom of the pipe. Segregation cannot be overcome but it can be minimized by rapid cooling.

Coarse crystalline structure or ingotism is inherent in metal that is cooled slowly from a high temperature. The size of the crystals depends upon the rate of cooling. Large crystals make the ingots likely to tear in rolling. The rolling process refines the grains and prevents the effects of coarse crystals showing up in the finished product, if it has been properly worked.

A mold having a rough surface causes resistance to the natural contraction of the cooling metal and produces checks or small cracks in the ingot skin. If the mold is improperly poured so that the metal is splashed against the sides of the cold mold where it sticks and oxidizes, the ingot will have scabs on its surface after it is stripped. These defects produce a seamy product. In plates they will form surface defects.

Slag inclusions may be formed by dirt in the ladle or mold, or slag may be formed by the oxidation of the metal in the ladle. Small slag inclusions do not have time to rise to the surface of the metal. In the finished product, slag inclusions are the source of surface blisters.

Pipes, blow holes, and segregations cannot be entirely prevented. Their bad effects can be minimized, however, by the use of aluminum to quiet the metal and by rapid cooling. Since slow cooling is necessary to minimize piping, careful study and exercise of judgment are necessary to secure the best quality in any lot of steel.

Heat treatment of ingots:- Study Article 607. Ingots are placed in the soaking pits in a vertical position. This is necessary because the ingot should be stripped as soon as possible so as to conserve the most heat and also so as to require a minimum of extra heating in the soaking pit. Since the interiors in the ingots when they are stripped are still soft the ingot must remain in the upright position in which it was cast. Otherwise the extent of the pipe may be increased and its position altered. The upright position also exposes the greatest surface of the ingot so that it will more quickly come to a uniform temperature.

General method of rolling:- Read Article 608. Rolling, as a method of shaping steel, is now most extensively used. Henry Cort is credited with having rolled the first steel in 1783. Other metals were evidently rolled before that time. Rolling is a very rapid method of shaping steel.

In the breakdown of the heavy ingots large mills are used. These reduce the ingots to lighter sections, in such simple shapes as round, square, and rectangular. When the ingot is reduced to a square section six inches ~~larger~~ on a side or to rectangular sections in which the widths are less than twice the thickness,

these sections are called blooms. If the section of the metal is square, and between 1 1/4 and 6 inches on a side it is called a billet. If in width the section far exceeds the thickness it is called a slab. Blooms, billets and slabs are cut into convenient lengths. Mills for the shaping of steel are named after the product they make; as blooming mill and slabbing mill. In England a mill making blooms is known as a cogging mill.

Rolling mills: Read Article 609. The various types of mills are described in this article. The rolls are illustrated in Figure 3 on page 561. They are made of cast iron, steel, or alloy mixtures. Rolls must be tough to withstand the shock produced as the piece enters them; they must have high transverse strength to work under the high pressures developed in rolling; they must be hard so as to have good wearing qualities; and they must be sound so that they will not develop surface defects, and thus cause the rejection of the finished products. Cast iron rolls are known as sand rolls and chilled rolls; alloy steel rolls are given the trade names of steel rolls and adamite rolls. Chilled rolls are expensive but they must be used where a high grade finish is required. A higher tonnage is obtained from these rolls than from any other kind. Chilled rolls for plate mills have been made as heavy as 40 tons. These require a mold about 23 feet in length. Besides being subject to violent impact and heavy pressure, rolls are unevenly stressed, and unevenly heated, and even over heated and then suddenly cooled. These are very severe conditions and they can be stood only by well made rolls.

Steel rolls, while they have the required strength, do not hold their finish under the high temperatures of rolling. They are seldom used for finishing rolls, but they are well adapted to the work of the blooming mills and heavy roughing stands. The adamite rolls have not yet been very widely used.

Plates:- Read Article 610. Plates are rolled in an ordinary mill and sheared, as indicated in this article, or they are rolled in a universal mill. Plates are known as sheared or universal mill plates, according to the method by which they were rolled. Sheared plates are not suitable for girder construction; universal mill plates with rolled edges are desirable for this purpose. Universal mill plates can be rolled to exact and uniform widths so that shearing costs are reduced, and furthermore, machining is frequently unnecessary. Moreover, universal mills turn out great tonnage so that universal mill plates are lower in cost than sheared plates.

Sheets:- Read Article 611 on the manufacture of thin steel sheets.

Pipes:- Read Article 612. The manufacture of seamless, but-welded, and lap-welded tubing is explained in this article.

Wire:- Read Article 613; it explains the manufacture of wire. Wire dies are made of steel plate and chilled iron. The latter are most extensively used in this country. They are extremely hard.

Forging and pressing:- Read Article 614. Shaping by hammer forging is a slow process. However it is a simple one and

was the first method used to shape metals. The first power hammer was built in England but the first steam hammer was a French invention. It was first operated in 1842. It was a single acting hammer in which the head or top was raised by steam. The invention of the double acting steam hammer, which employed steam power on the downward stroke, was a decided improvement. The first one was built in Pennsylvania, in 1888.

The suddenness of the hammer blow tends to localize the effect and hence only the exterior of the metal is refined. If each blow of the hammer reduces the metal to a considerable degree, or if the metal is thin, this method will produce material that is superior to rolled steel. Small objects made of high-grade steel, such as stock for cutlery and tools, are usually hammered into shape. The making of drop forgings is explained in the text.

Forging presses are an English invention of about 1860. They were introduced into the United States in 1887. The sizes and working pressures are given in Article 614. The action and effect of pressing is different from that of hammering. Pressing is so slow that a kneading action takes place and the effect, therefore, penetrates deep into the steel instead of refining only the surface as does hammering. Both methods improve the quality of steel.

Steel castings:- Read Article 615. During recent years there has been much development in the quality of steel castings

and also in the types of objects cast. Large castings which are subjected to heavy stresses are now made of cast steel. Locomotive frames, stern frames for ships, anchors, buckets, and bucket tumblers for gold dredgers are some of the articles made of carbon and alloy steels in the form of castings. The Columbia Steel Company at Pittsburg, California, is the largest steel casting plant on this part of the Pacific Coast. Most of their steel is made in basic open hearth furnaces of steel scrap. They also operate a small acid open hearth furnace.

The production of good steel castings requires considerable foundry experience. Many complex foundry problems are involved. In order to produce sound castings it is necessary to have large sink heads so placed in the mold that the hot steel is available to fill any part of the casting where there is a tendency on account of too rapid cooling, to produce a cavity. Due to the excessive shrinkage of steel castings there are severe internal stresses set up in the cooled product. These stresses can be relieved and the structure of the casting refined by proper annealing. Steel castings must be carefully designed so that there are no sharp angles in the outline. The molds for large castings must be well reinforced to withstand the heavy loads of molten metal.

Omit Article 616 on page 567. The statistics given in this article are not important.

QUESTIONS

1. What methods are used in shaping steel?

2. How do the various processes employed in shaping steel affect its quality?

3. What is an ingot, a bloom, a billet?

4. What is a pipe? How is it caused? Can its occurrence be prevented? How does it affect the metal in a rolled section?

5. What is segregation and how is it minimized?

6. How are blow holes formed? Can their formation be prevented?

7. What is a universal mill?

8. What are the rolls of a steel mill made of?

9. How is steel tubing made?

10. How are the cooling stresses in steel castings relieved?

11. Why is it necessary to soften wire during the drawing process? How is this softening accomplished?

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Materials of Engineering Construction

Civil Engr-8 B. Professor C.T. Wiskocil

Assignment 21.

FORMATION AND STRUCTURE OF ALLOYS

Alloys in general:- Read Articles 617 to 626 inclusive.

Reasons for alloying metals are given in Article 617. By the alloying process, desirable properties may be improved and undesirable properties may be lessened. An alloy may be tougher, harder or more ductile than any of the constituent metals. The cost of production may be decreased by introducing cheaper metal into the alloy and by producing an alloy that is more easily worked (cast and machined) than the metals from which it is made.

A mixture is defined in Article 618. In a mixture the two or more ingredients do not bear a fixed proportion to one another, and however thoroughly com-mingled maintain a separate existance. The constituents of a mixture can always be detected by microscopic examination.

As indicated in Article 619, elements combine in definite fixed proportions to form compounds. The formation of chemical compounds is not of much importance in the consideration of iron and steel.

Solid solutions are described in Article 620. The most familiar examples of solutions are in the form of liquids. However it should be remembered that every mixture of gases is a solution

and that even metals may form solutions which, when they solidify, are known as solid solutions. The solidification of a liquid solution does not necessarily produce a solid solution. If the constituents separate upon solidifying the solid is a mixture. In a mixture the individual ingredients may be seen although in some cases of thorough commingling the use of a microscope is necessary. But if the constituents remain completely merged so that they retain in the solid state the essential characteristics of a solution, the solid is called a solid solution. The solid solution must possess such uniformity of structure that the constituents cannot be detected by physical means such as microscopic examination, and furthermore the combination of the component parts in any proportion must be possible. In these regards it differs from a compound. Glass is a solid solution; an alloy of gold and silver is another. In the latter case the elements combine into the same kind of crystal no matter what their relative amounts may be.

Study Article 621 carefully. As explained in this article most alloys of steel are formed by fusion. Low carbon steels are given a hard exterior surface by the method of diffusion in which the diffusing material may be solid, liquid or gas. The term miscible used in this article means capable of being mixed; mixable

Read Article 622 on allotropy. Allotropy may be defined as the ability of an element to exist in two or more conditions,

which are distinguished by differences in properties. Carbon, for instance, may exist as diamond, charcoal, lampblack, and black-lead. Iron has several allotropic forms. See Article 658 on page 590.

Study Article 623 on the crystalline structure of metals. Metals are inherently crystalline, and it is, therefore, incorrect to speak of the crystallization of iron and steel as a result of fatigue. See Article 822, on page 771.

The strength and toughness of metals are influenced by the shape and size of the crystals as well as by the chemical composition of the metal. Steel of high strength has very small crystals and they can be detected only under a powerful microscope. The microphotographs on pages 596 and 597 will illustrate this point. The effect of heat treatment on the shape and arrangement of crystals is shown in the illustrations on pages 628, 629 and 630. Until recently the examination of the fresh fracture of iron and steel was the only method of classifying the product. Even at the present time, melters in charge of open hearth furnaces cast, break and examine the fresh fracture of small bars of metal, in order to watch the elimination of the impurities from the bath, and at the end of the heat to determine the carbon content, which they predict to within a few points. If the carbon content of a piece of steel is known, skilled inspectors can determine approximately by its fracture the heat treatment it has received, and its probable strength and toughness.

As explained in Article 623, when steel passes from the liquid to the solid state, the molecules of the various constituents arrange themselves to form small bodies having regular geometrical outlines. This phenomenon is called crystallization. Individual crystals may be octahedral or cubical bodies, and under ideal conditions of high fluidity, absence of foreign particles, slow cooling, and undisturbed liquid, will form perfect geometric shapes. However, under conditions of manufacture, steel solidifies into imperfect crystals with irregular form, which are sometimes called grains.

Read Article 624 on the effects of solubility relations in alloys. Since no examples are given it may be rather difficult to comprehend the information given. If this article is reviewed after the study of Articles 627 to 636 inclusive, in which definite cases are taken up the more general statements will be understood.

Study Article 625. Microscopic examination and examination of heating and cooling curves afford the most important means of investigating the properties of pure metals and their alloys. The method of obtaining cooling curves is explained. It should be remembered that the temperature of the material must be observed and recorded at uniform intervals of time during a uniform heating or cooling. This method will produce diagrams like those shown in Figure 2, on page 573.

If a body undergoes an abrupt change in physical properties

(as when it melts or vaporizes), a quantity of heat is absorbed or given off without changing the temperature of the body. The heat absorbed during the change in state of a body is called latent heat. Latent heats will have a marked affect on the cooling curves. If all the heat given off by a body is furnished at the expense of the temperature of the body, that is, if it disappears as sensible heat, the cooling curve will be smooth and continuous as (a), in Figure 2, on page 573. Horizontal portions or arrests in the cooling curve indicate that the temperature is maintained by the evolution of a certain amount of latent heat. See (b) in Figure 2. The curve below the freezing point or arrest in the cooling is similar to that in Diagram (a). The cooling curve for water should be familiar, since it falls within ordinary experience. When water is subjected to a low temperature it will lose heat steadily until the freezing point is reached at zero degrees Centigrade. At this point the water will continue to lose or radiate heat, but its temperature will remain at zero until all the water is changed into ice. During this second period radiated heat is given off at the expense of the so-called latent heat of fusion of ice. Further radiation is at the expense of sensible heat and the temperature of the ice falls until it becomes that of the surrounding medium. The cooling curve of liquid antimony or any pure metal near its solidification point is very similar to the cooling curve of water. The curve is similar to that in diagram (b) in Figure 2.

Study Article 625 on cooling curves. Temperature - time diagrams such as are shown in Figure 2 are not well adapted to show small evolutions of heat in an alloy such as steel. An inverse rate curve, however, will magnify the changes in direction of the cooling curve and permit a more accurate determination of critical temperatures. The data for an inverse-rate curve are obtained by reading and recording the time required for the body to cool through equal intervals of temperature. The following is an inverse-rate cooling curve for 0.4% carbon steel;

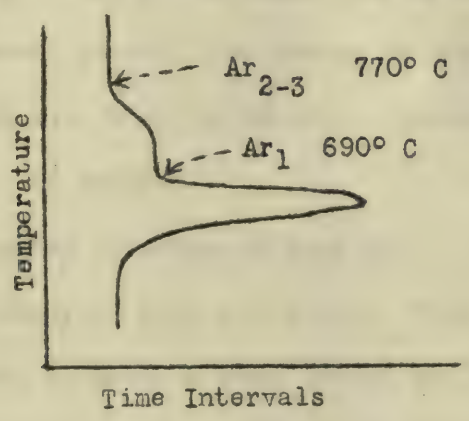
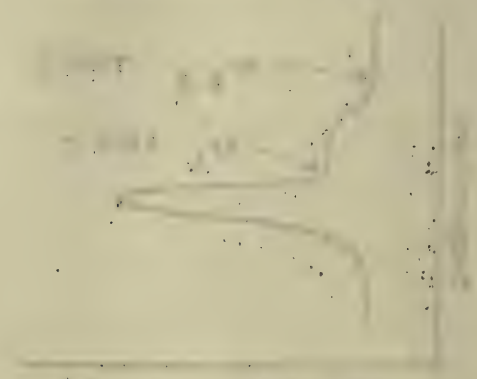


Figure 1.

The equilibrium diagram for alloys of carbon and iron is obtained from inverse-rate cooling curves for a complete series of alloys. The critical points are more readily determined from these diagrams than from the ordinary cooling curve. An ordinary cooling curve for 0.4% carbon steel is as follows:



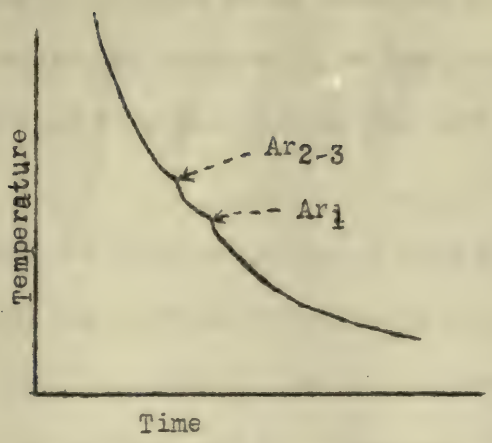


Figure 2.

The critical points are scarcely perceptible, and if the curve were drawn from experimental points, the breaks or arrests in the curve would be determined only with difficulty. The superiority of the inverse-rate curve is evident.

An equilibrium diagram is shown on page 591. It is of great importance in the study of iron and steel. Other names for this diagram are given in Article 626, about the middle of page 574. Equilibrium diagram is as good a name as any of those listed.

Study Articles 627 to 630. The freezing of binary alloys which solidify by selective freezing is fully explained in these articles. The constituents in this type of alloy separate in freezing. Lead and tin form such an alloy. An equilibrium diagram for water and salt is like that shown on page 575. That part of the iron-carbon equilibrium diagram (shown on page 591) to the right of the 2% carbon line is analagous to that of the binary alloys in which the state of solution is not maintained in

the solid state, namely to those which solidify by selective freezing. Primary austenite which will be described later, instead of iron, separates from the melt to the left of the eutectic point.

The temperature at which an alloy of this type begins to solidify depends upon the relative percentages of the constituents. If this is, say, the point X, in the diagram in Figure 3, freezing will begin at temperature j. Remember that only the melt or mother liquor is enriched in constituent B, since crystals of W separate out of the solution. The composition of the alloy always remains as represented by the percentages at the point X. Note that the cooling curve for an alloy of the composition X is represented in Figure 2, diagram (d), on page 573.

The term eutectic is used for the first time in this article. It is taken from a combination of the two Greek words which mean "well" and "melting". The meaning of the term eutectic is taken as easily-melted, or literally, low-melting. A mother liquor which always has the same composition for given constituents, and a constant freezing point, and which remains liquid longest, or in other words which has the lowest melting point, is called the eutectic of the given constituents. The fact that a eutectic has a constant melting point and hence a constant composition led early investigators to believe that it was a chemical compound. Later it was shown that its constituents were not in any simple molecular ratio. Furthermore microscopic examinations of

eutectics (see the illustrations on page 597), showed that they are not homogeneous substances, but a mechanical mixture of minute cyrstal grains of the constituents.

Study Articles 631, 632, and 633 on the binary alloys in which the constituents in solution in the liquid remain in solution in the solid state; in other words those in which they form a solid solution. The diagram in Figure 8 on page 579 illustrates the binary character of the gold-silver alloys, which are of this type. The regions II and IV to the left of the 2% carbon content as indicated by the point S in the iron-carbon equilibrium diagram in Figure 1, on page 591, is a region of non-elective freezing and shows a situation analagous to the freezing of the alloys discussed in this article.

Study Articles 634, 635, and 636. These articles, together with similar ones previously studied, form the basis for a study of the iron-carbon equilibrium diagram which is of importance. The area of this diagram to the left of the 2% carbon content line shows selective freezing from a solid solution with the formation of a eutectic. To differentiate this latter eutectic from the one at point E in the diagram on page 591, which is a true eutectic, since it is formed from a mother liquor or solution, it is given the name eutectoid, a term which is interpreted as meaning "something of the nature of a eutectic".

Be able to draw characteristic equilibrium diagrams and explain the process by which freezing takes place.

The discussion of alloys of more than two components need not be studied. It would be of use in the discussion of alloy steels but in this text they are not treated in much detail.

The information in this assignment is rather different from that in any so far studied. The student should put forth an effort to master the fundamental principles discussed in the text. No thorough discussion of iron and steel can be made without use of the equilibrium diagram and before it can be used with facility the fundamentals given in Chapter XX in the text must be understood.

QUESTIONS

1. How does a mixture differ from a solution? From a compound?
2. What is a solid solution?
3. What is a eutectic?
4. What is a eutectoid?
5. Define allotropy. What is its relation to the study of iron and steel?
6. Draw a cooling curve for water near its freezing point.
7. What is an inverse-rate curve? What is it used for?
8. Explain the reason for the horizontal parts or arrests in a normal cooling curve.
9. Would you expect to find perfectly shaped crystals in commercial steel? Why?
10. Draw an equilibrium diagram for a binary alloy and explain how it freezes if the state of solution is not maintained in the solid state.
11. Why are metals alloyed?

UNIVERSITY OF CALIFORNIA EXTENSION DIVISION

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Materials of Engineering Construction

Civil Engr-8 B. Professor C.T. Wiskocil

Assignment 22.

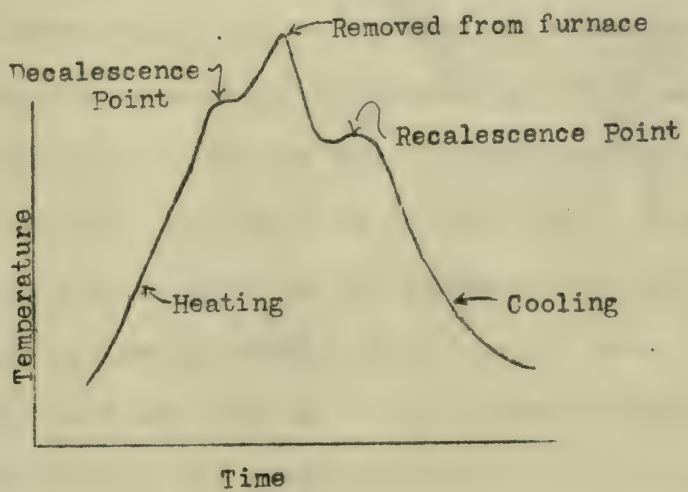
THE CONSTITUTION OF IRON AND STEEL

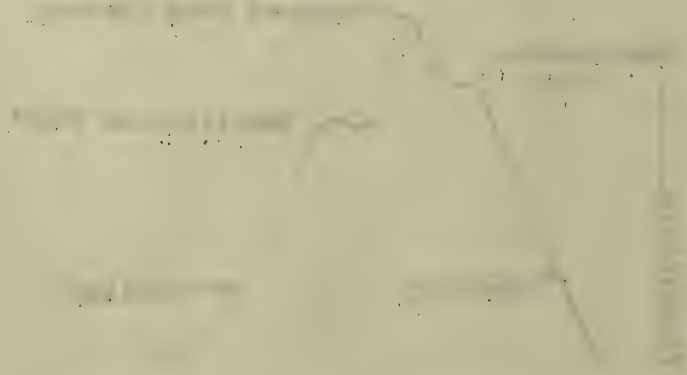
The necessity for alloying pure iron is briefly stated in Article 639. The reasons for alloying metals in general were given at the beginning of the previous assignment on the "Formation and Structure of Alloys". In this discussion, pure steel will be considered as an alloy of iron and carbon. In ordinary steels there are, besides these elements, sulphur, manganese, phosphorus, oxygen, and silicon, together with traces of copper, aluminum and nitrogen. Carbon and other elements added purposely are essential ingredients; the others are impurities. The marked effect that additions of carbon to pure iron have on the resultant alloy are due to the changes caused in the structure. This is very evident from microscopic studies of these alloys. See the illustrations on page 596. Because of the effect carbon has on the physical and mechanical properties of steel, its presence is necessary in very small amounts only. Even in the hardest tool steels it does not exceed 1.5% by weight. Carbon is usually measured in hundredths of one per cent, each unit (or 1/100 of one percent) of which is spoken of as a point. A steel having a carbon content of 0.25% would be designated as 25-point carbon steel.

Steel was defined in Assignment 19 under the subject Manufacture of Steel. You should be able to give definitions in Articles 640 to 655 at the time the materials in question are discussed and should make no attempt to remember definitions of materials that are not discussed. Furthermore, you should not memorize definitions in the words of the text, but should define materials and processes in your own words. Read over Articles 640 to 655 inclusive and see how your own definitions agree with those in the text.

Read Article 656 but omit the table. The equilibrium diagram for alloys of iron and carbon will now be taken up in detail. The remainder of the chapter should be carefully studied.

The critical temperatures for pure iron are given in Article 658. Critical temperatures were referred to in the previous assignment, number 19, under the discussion of cooling curves. If eutectoid steel is considered it will be found to have only one critical point. The heating and cooling curve would be approximately as follows:





As explained in the text the critical points are higher on heating than on cooling. The recalescence point for eutectoid steel (0.9% carbon) is about 690 degrees Centigrade. Since the structural changes which occur do not take place suddenly the critical temperature or critical point is more properly designated by the term critical range. When eutectoid steel passes through its critical range during the process of cooling the temperature of the steel will actually rise if the conditions are favorable. An attempt has been made to show this condition in the diagram just given. In the case of pure iron the change in rate of cooling is not very marked. There is no actual rise in temperature, or recalescence, at the critical temperature which occurs about 900° Centigrade. The lower critical range at 760°C. is less marked than the first. Below 760° the steel cools normally to atmospheric temperatures. In a low carbon steel, say one having 0.1% carbon, there are three thermal retardations. The most pronounced is at 850° C, the second about 760° and the third near 700°. The last two are quite indistinct. As carbon is added to the alloy the two upper critical temperatures, found in the 10-point carbon steel, will approach each other and at carbon contents of .35 to .40% will merge into one, so that these steels have only two critical temperatures, one at about 740° and the other at about 700°. Further additions of carbon seem to cause the two remaining critical temperatures to merge into one at about 0.6% carbon and over. Theoretically the merging should not occur until the eutectoid composition is reached at 0.9% carbon. The actual determination of two critical

temperatures, when they are close together, is very difficult, and this fact accounts for the apparent merging with the lesser percentage of carbon.

The critical ranges are illustrated in the equilibrium diagram. The diagram on page 591 refers to the critical ranges on cooling. All critical ranges are denoted by the letter A. To indicate the period of heating the A is followed by a small c, which stands for the French word "chauffage" which means heating. Ar denotes a critical temperature on cooling, the r being the abbreviation for the word "refroidissement", meaning cooling. The designation Ac and Ar are further modified by the numerals 1, 2 and 3 to signify the critical ranges in the order they are encountered; thus, Ac_1 means the first critical range encountered upon heating the steel.

In carbon steels there is a difference of about 30 degrees between the critical temperature on heating and the critical temperature on cooling. Theoretically these temperatures should be the same. It has been proved that one important factor causing this temperature lag is the ordinary phenomenon of hysteresis. The process of slow heating and cooling bring these critical temperatures closer together. Two other minor causes for the difference are the impurities contained in the steel The maximum temperature to which the steel is heated is another factor which causes a temperature lag between the critical points. For ordinary commercial steels and usual practice these latter causes are of no consequence.

Cementite and ferrite, two important constituents of steel, are defined in Article 659. Ferrite is soft, weak, and ductile. Its tensile strength is estimated to be about 40,000 lb. per sq. in. It is strongly magnetic and has a high electric conductivity. It has no hardening power. Ferrite appears best in microphotographs of low carbon steel, containing from 10 to 30-point of carbon; in these microphotographs it has a white color. See (b), (c), and (d) in Figure 3 on page 596.

When steels are cooled from a high temperature all the carbon is combined with iron in a chemical compound which in microphotographs is always referred to as cementite. Steel made by the cementation process contains considerable cementite (Fe_3C). Little is known of its actual properties except that it is the hardest constituent of steel. It will scratch glass but not quartz. It is very brittle. Cementite is thought to have a high shearing strength but to be weak in tension. It occurs free in hypereutectoid steels; see (g) and (h) in Figure 3 on page 596.

Pearlite is defined in the first paragraph on page 592. The eutectoid of steel is called pearlite because of its resemblance to mother of pearl. It is a mechanical mixture of minute crystals of cementite and ferrite, always in definite proportions as given in the text. It contains approximately 0.9% carbon. Pearlite commonly occurs in slowly cooled steels in the lamellar phase which is shown in (b) of Figure 4 on page 597, in which

it is composed of alternate layers of ferrite and cementite. Note the high magnification necessary to bring out the required detail in the illustration referred to. Besides existing in globular form, as shown in (a) of the same figure, pearlite has been found to exist in three other, but less important, forms. The size of the grains has a marked effect on the strength of pearlite. Under normal conditions its maximum tensile strength is estimated to be over 100,000 lb. per sq. in. It is about 2.5 times harder than ferrite, but it is not hard enough to make tools which require a cutting edge.

Austenite (named after Sir Roberts-Austen) is a substance determined microscopically as a constituent of steel under certain conditions and regarded as a solid solution of carbon or iron carbide in iron. See paragraph IV on page 591 in the text.

Be able to draw the iron-carbon equilibrium diagram given on page 591. Include in this diagram as much information as possible. In the construction it is necessary to remember the location of certain important points, such as A, G, O, P, S, and E. When these points are located the main lines in the diagram can be sketched in. The eutectic contains about 4.3% carbon. This is point E in the diagram. For hyper-eutectic alloys graphite separates from the melt along ED until the point E is reached, when the eutectic solidifies. It might be expected that iron would separate from the melt along the line AE. This, however, is not the case, but a mixture of iron and carbon containing approximately 2% carbon and known as primary austenite sepa-

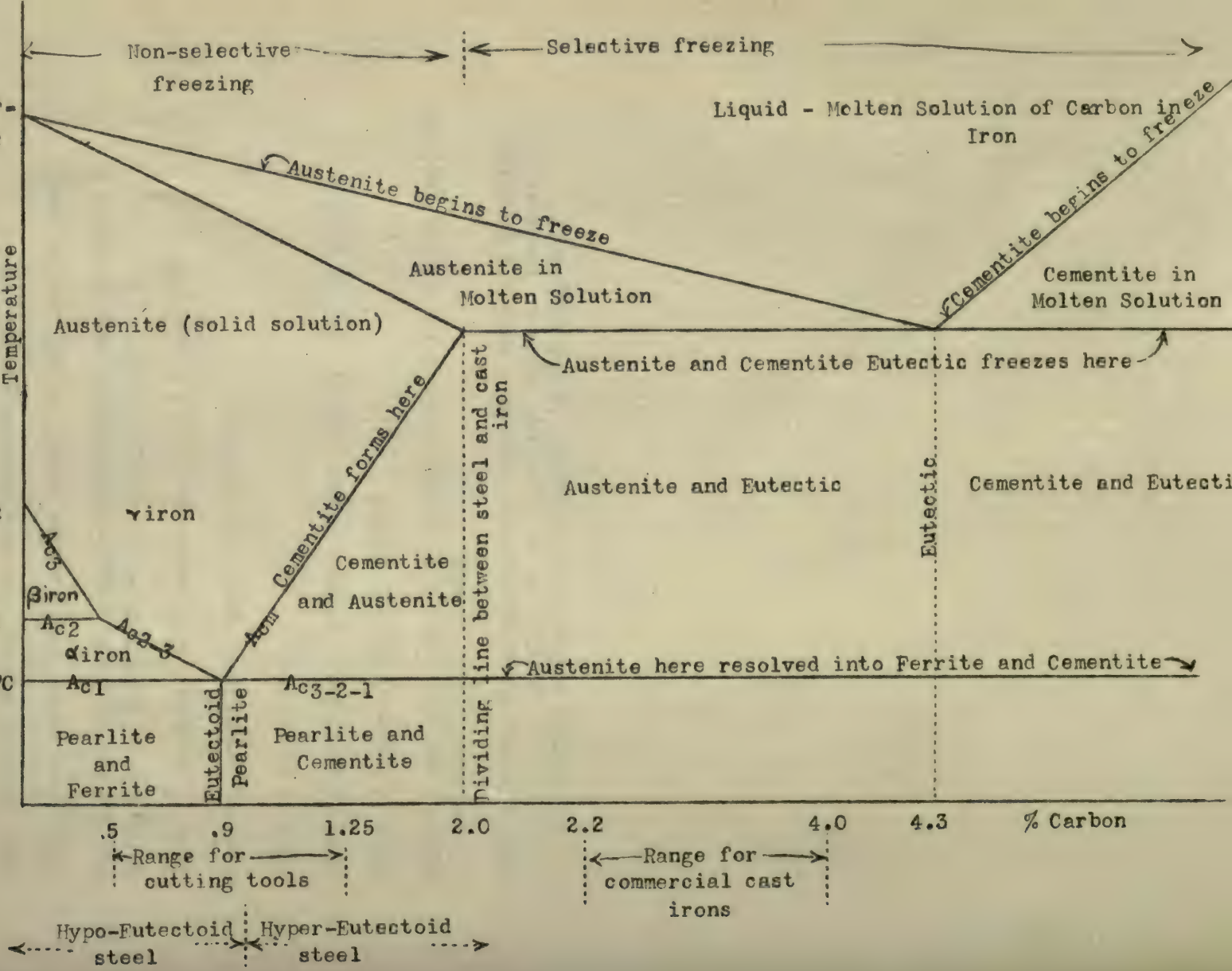
rates from the melt to the right of the point S in the diagram. In this portion of region II the iron-carbon alloys exhibit the phenomenon of selective freezing, as do the lead-tin alloys. See Figure 3 on page 575. To the left of point S, or in alloys having less than 2% carbon, the freezing is non-selective, similar to that of the alloy whose equilibrium diagram is shown on page 579. This kind of freezing is characteristic of the gold-silver alloys. Consider an iron-carbon alloy having about 1.5% carbon at a temperature of 1500° C. It is a solution of carbon in iron, which if allowed to cool will begin to crystallize when the temperature reaches the line AE or about 1400° C. Solidification will continue until the temperature reaches a point on the line AS, or about 1220° C, at which point the solution is exhausted and the entire mass becomes solid. Each crystal that separates from the melt will contain 1.5% carbon; therefore, the entire mass is a solid solution of carbon and iron. It is also known as primary austenite.

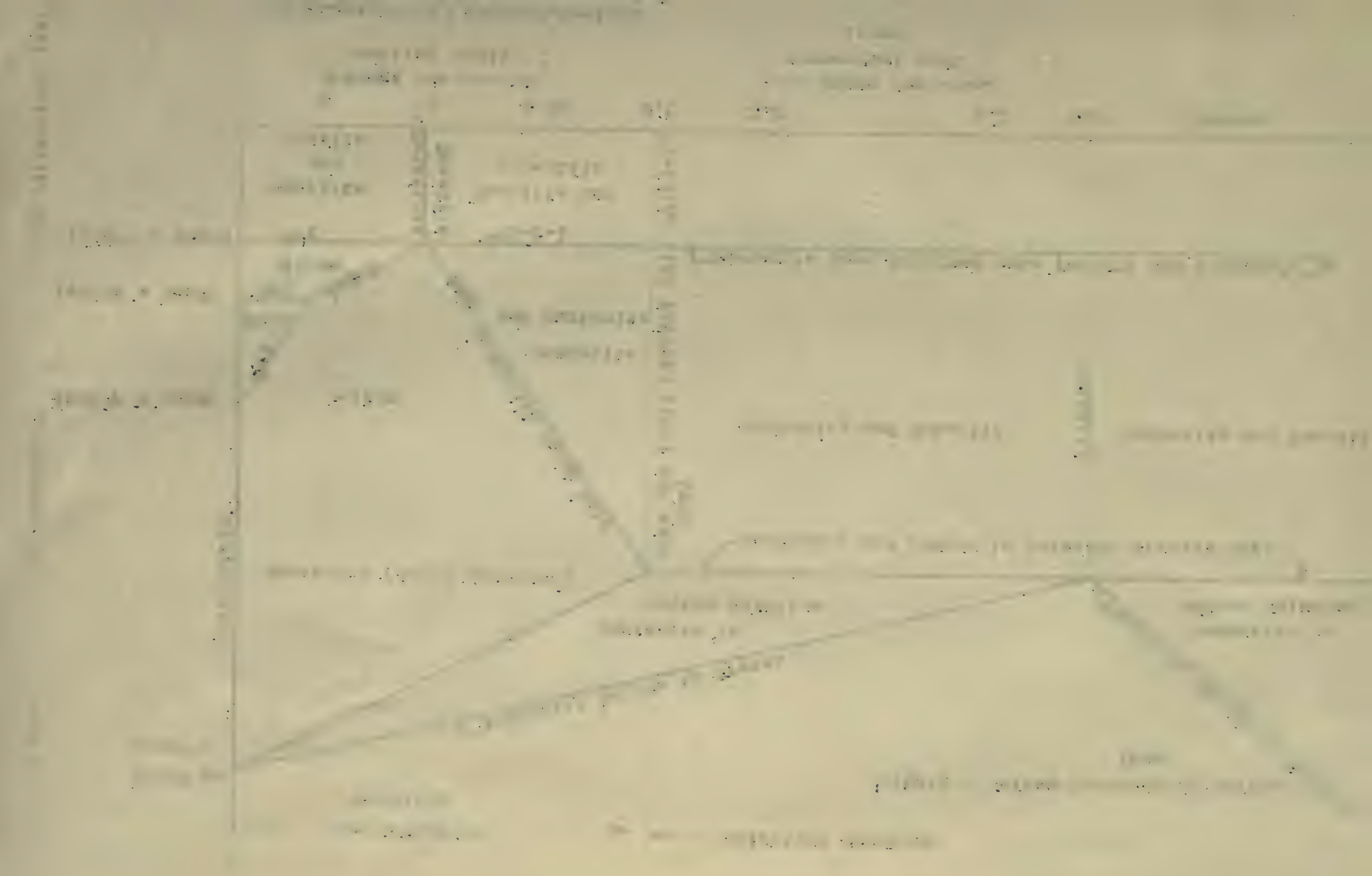
During the cooling of primary austenite in the region IV, below the line AS, it undergoes changes similar to those which occur the cooling of a liquid solution. Along the line PS, for alloys having more than .9% carbon and known as hyper-eutectoid steels, cementite is precipitated. For alloys having less than .9% carbon, that is hypo-eutectoid steels, pure iron or ferrite is thrown out along the line GOP until the eutectoid composition is reached. At this point both ferrite and cementite are precipi-

tated at the same time and the eutectoid pearlite is formed. The change from austenite to pearlite is not instantaneous; but, as will be explained under the discussion of heat treatment and tempering, the austenite may pass through a series of stages in which it is known as martensite, troostite, and sorbite; finally it becomes pearlite. If a steel which contains 0.9% carbon is cooled slowly from a point above its critical temperature, so that it will have an opportunity to pass through all transition stages, it will consist entirely of pearlite and be known as a eutectoid steel.

Steel having above 0.3% carbon is supposed to have the ability to harden but edge tools are usually made from low carbon steels, in which the carbon ranging from 50 to 125 point. While 2.0% is the theoretic division line between steel and cast iron, commercial tool steels rarely exceed 150 point carbon (1.5% carbon). Commercial cast irons usually range between 2.2 and 4.0% carbon.

Most of the information discussed in connection with the iron-carbon equilibrium diagram is given in the following sketch:


Non-selective freezing
Selective freezing
2730° F
1500° C
Liquid - Molten Solution of Carbon in Iron
Austenite begins to freeze
Cementite begins to freeze
Austenite in Molten Solution
Cementite in Molten Solution
Temperature
Austenite (solid solution)
Austenite and Cementite Eutectic freezes here
Cementite forms here
Dividing line between steel and cast iron
1650°F = 900°C
γiron
Austenite and Eutectic
Eutectic
Cementite and Eutecti
Cementite and Austenite
βiron
1420°F = 760°C
Ac2
Ac3-2
αiron
Austenite here resolved into Ferrite and Cementite
1270°F = 690°C
Ac1
Ac3-2-1
Pearlite and Ferrite
Eutectoid Pearlite
Pearlite and Cementite
.5
.9
1.25
2.0
2.2
4.0
4.3
% Carbon
Range for cutting tools
Range for commercial cast irons
Hypo-Eutectoid steel
Hyper-Eutectoid steel



QUESTIONS

1. What is meant by the critical temperature of steel?

2. Define the term "recalescence point" as applied to steel.

3. Why are the critical temperatures higher when steel is being heated than when it is being cooled?

4. What is ferrite? What are some of its properties?

5. What is cementite? Write its formula.

6. What is austenite?

7. What is pearlite? In what forms does it usually exist?

8. What is hyper-eutectoid steel?

9. What is the usual range in carbon content for steels used in the manufacture of edge tools?

10. Draw a carbon-iron equilibrium diagram. Mark all important points and areas. It is important that the temperatures and carbon contents be indicated on the diagram.

UNIVERSITY OF CALIFORNIA EXTENSION DIVISION

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Materials of Engineering Construction

Assignment 23.

Civil Engr-8 B. Professor C.T. Wiskocil

PROPERTIES OF WROUGHT IRON

Structure:- Read Article 664. The structure of wrought iron is clearly shown in Figure 1 on page 598. The greater part of wrought iron is pure ferrite; in fact, this material approaches nearer to pure iron than any other commercial form of iron. In both the transverse and longitudinal sections the characteristic slag inclusions can be seen. In the longitudinal section, the slag follows the direction of rolling in dark lines of varying thickness; and in the transverse section it appears as irregular dark areas. An examination of the structure of wrought iron, which can be made in several ways, is the only positive method of distinguishing this material from low carbon steel. In the wrought iron a small amount of carbon is always present and this combines with the ferrite to form cementite. The cementite is present in such small quantities that none remains in the free state; it is, however, present in the form of pearlite. The pearlite is not conspicuous but is distributed in small isolated areas between the grains of ferrite. Normal wrought iron contains about 2.5% slag, 96.5% iron, and the remaining 1% silicon, phosphorus, sulphur, carbon and manganese.

When wrought iron is tested in tension, the fracture reveals a fibrous structure. As explained in this article the fracture of

wrought iron which is impure or adulterated (with steel scrap) may have a crystalline appearance. This type of fracture may occur, too, when the load is suddenly applied so that the fibers do not have time to draw out as under conditions of the normal tensile test.

Defects:- Read Article 665. Since the impurities usually combine with the slag they are not as important as in the case of steel. Sulphur and phosphorus are the principal impurities.

Tensile strength:- Read Articles 666 and 667. As would be expected, the tensile strength of wrought iron depends upon the relation between the direction of the fibers (which in turn depends upon the direction of rolling) and the direction of the applied stress. Even when the tensile stress is parallel with the fibers the strength of wrought iron is quite variable. An average value may be taken as 50,000 lb. per sq. in. ultimate, with a proportional limit of about 30,000 lb. per sq. in. The strength when stressed normal to the direction of rolling, as may occur in plates, may be taken as 3/4 of the values given for the strength parallel with the fibers.

The ductility is also quite variable. The average may be taken as 35 %, measured in terms of the elongation in a 2-inch gage length.

The stress-deformation curves resemble those for mild steel.

Tensile strength across the grain:- Read Article 667. As already stated this may be taken as 75 % of the strength parallel with the grain. The text gives more detailed information

on wrought iron than is warranted by its importance.

Compressive strength:- Read Article 668. The ultimate strength of ductile materials like wrought iron is taken as the proportional limit strength; 30,000 lb. per sq. in.

Shearing strength:- Read Article 669. If wrought iron were one of the important structural materials it would be necessary to remember the details of information such as are given in this article. Since it is not, it is sufficient to note that the shearing strength is about the same as the tensile strength, 30,000 lb. per sq. in., and that it varies in a manner similar to that exhibited by the tensile strength.

Modulus of elasticity:- Read Article 670. Take the average modulus of elasticity as 27,000,000 lb. per sq. in.

Effects of overstrain; - Read Article 671. Overstrain is produced by cold working, such as rolling, hammering and pressing at a temperature below 690° C. In general the effect of overstrain is to raise the ultimate strength and decrease the ductility.

Toughness of wrought iron;- Read Article 672. Toughness is determined by the impact test. The toughness of wrought iron and mild steel are about the same; no quantitative value is assigned.

Wrought iron chains:- Read Article 673. The strength of wrought iron chains may be taken as 1.6 that of the material from which the links are made.

The welding of wrought iron:- Read Article 674. One of the most important properties of wrought iron is the ease with which it can be welded. Low carbon steel, when the impurities are low, can be welded quite as easily as wrought iron, but other steels are not so readily welded. The welding temperature is close to the melting point, at which point or range in temperature the iron is very plastic. But at this high temperature two conditions arise which affect the weld. One affects the operation of welding while the other affects the strength of the weld. In the first case, the oxygen in the air combines readily with the iron at welding temperatures and the coating of iron oxide which forms on the surface prevents a perfect union of the parts of the weld. In the second case, welding temperatures also cause a coarse crystalline structure which decreases the strength of the metal and increases its brittleness.

The oxide or slag which forms on the metal is forced out of the weld when the surfaces are made convex, as indicated in Figure 8 on page 607. The parts come into contact at the center and as the joint is hammered or forged, the slag is squeezed out. This action is facilitated by the use of a flux such as borax which makes the slag more liquid. Sand is used as a flux in welding steel.

Coarse crystallization can be prevented by working the metal until it has cooled through its critical range in temperature. The metal just at the weld is usually thoroughly worked by hammering so that the welds as a rule do not break at the joint but some

distance back. As welding is usually done the pieces are only slightly scarfed and the joint only is hammered. If a bar welded in this manner is bent, it will usually break just outside the weld. Blacksmiths often assert that the weld is stronger than the bar. The weakness in the bar, however, has been developed by the method of welding. If the ends of the bar to be welded are first heated to a moderate welding temperature and stove up (hammered on the ends to make the section thicker) and if a well beveled scarf is made, instead of the short, blunt one usually put on, the chances for a better weld are much improved. The ends are then reheated to welding temperature, the flux applied and the weld made in the usual manner. If the ends have been properly stove up, the bars will have to be hammered where the grain size has been increased by the high temperature, so that when the joint is worked down to size it will have been hammered well back from the center of the weld, on account of the long scarf, and no weak spots will be left. The bar will then have a uniform structure and should be equally strong throughout its length. Electric heating is more efficient than forge heating and power forging produces a better weld than hand methods.

Methods of distinguishing wrought iron from soft steel:-

Read Article 675. Methods for distinguishing wrought iron from steel have been discussed in Assignment No. 19. It is proper to emphasize at this time that the only positive method of identifying wrought iron is by an examination of its structure. This can be

made by methods suggested in this article or by the regular microscopic methods.

PROPERTIES OF STEEL

The principal factors which influence the properties of steel:- Read Article 676. The quality and mechanical properties of steel are affected by (a) the method of manufacture. (b) the composition, (c) mechanical work, and (d) the heat treatment. It must be remembered that while these factors are discussed separately, all of them may have an effect on the quality and properties of a given piece of steel.

Effect of carbon:- Read Articles 677 to 685 inclusive. This element is employed as the controlling constituent in regulating the properties of common steels (so called straight carbon steels). The effect it has on the mechanical properties is discussed in detail in the text. Its most important influence is on the strength, hardness and ductility of the metal. Heat treatment, which will be discussed separately, has a marked effect on carbon steels. Beginning with pure iron which is soft and ductile, additions of carbon to normally cooled steel increase the hardness and strength and decrease the ductility, until eutectoid composition (0.9 % carbon) is reached. For each 10 points (1/10 of one per cent) of carbon added, the yield point is raised about 3,990 lb. per sq. in., the maximum tensile strength is increased about 9,360 lb. per sq. in., and the per-

centage elongation is reduced about 4.3 %. Above this point further additions of carbon result in increasing hardness and strength but more rapidly decrease the brittleness. The use of high carbon steel is restricted to products in which great hardness is the principal requirement and toughness and ductility are not so necessary. Commercial steels rarely exceed 1.20 % carbon. Straight carbon steels most generally useful in the hardened state have carbon contents ranging from .9 to 1.2 %; they are sufficiently hard for most uses and yet are not brittle to an objectional degree.

The general shapes of stress-deformation curves as influenced by the carbon content are given on pages 611 and 612. Note that the slope of the curve, which determines the modulus of elasticity, is not affected by changes in the carbon content. The results shown agree with the statements in Article 681. The average value for the modulus of elasticity may be taken as 30,000,000 lb. per sq. in. for all steels and for both tension and compression.

Average figures should be remembered. Take ordinary structural steel (rolled ~~mild-carbon~~ steel) which has an average carbon content of approximately 0.2 %. Its proportional limit is 30,000 lb. per sq. in. and its ultimate tensile strength is 60,000 lb. per sq. in. The compressive strength may be taken as the proportional limit, which is the same in tension and in compression, 30,000 lb. per sq. in. Its ductility as measured by the elongation is about 35 %.

Read Article 683 carefully. It explains why it is impossible to determine a yield point in high carbon steels. The drop-of-the-beam is well adapted to the determination of this point in the case of low carbon steels. This is also clearly shown in the diagrams on pages 611 and 612 previously referred to. In the strict interpretation of the term, high carbon steels do not have a yield point. The proportional limit can be obtained only with an extensometer.

THE EFFECT OF IMPURITIES

Read Articles 686 to 693 inclusive. A great deal has been written, with considerable difference of opinion, on the effect of various elements on the properties of steel. Manganese while it is listed in the text as an impurity, is unquestionably beneficial. Oxygen, which is not mentioned in the text in this particular article, is decidedly harmful. The effects of sulphur and phosphorus are considered to be harmful but opinion seems to be changing in this respect. Recently a committee organized jointly by the A.S.T.M. and the U.S. Bureau of Standards, and composed of representative engineers and investigators has been studying the effect of sulphur and phosphorus on the properties of rivet steel.

Influence of oxygen:- Oxygen causes both red shortness (or hot-shortness) and cold shortness in steel. The terms red-short or hot-short are used to designate a condition of brittleness in the hot metal. Cold-shortness is the term used to designate

brittleness at ordinary temperatures. These terms are used principally in connection with the process rolling. As little as .03 % of oxygen produces brittleness under impact. Large amounts of oxygen are not necessary to produce harmful effects. Overblown Bessemer steel without deoxidization contains only .15% oxygen, yet this renders the metal unfit for use.

Influence of manganese:- Read Article 690. Manganese is a powerful deoxidizing agent. That which is left in the steel after deoxidizing it causes it to roll and forge better and also slightly increasesthe tensile strength and hardness. As was brought out in the discussion under Sulphur, in Article 689, manganese combines with sulphur to form manganese sulphide. For manganese to exert its most beneficial effect it should be present in amounts greater than 1.7 times the amount of sulphur:(the proportion indicated in the text) About five times more manganese than the amount of sulphur present should be used.

Influence of sulphur:- Read Article 689. In the form of ferrous sulphide this element will cause red-shortness but it can be neutralized by manganese so that it is comparatively harmless. The opinion has been expressed that sulphur up to 0.1 % does not effect the strength and ductility of steel. The results to be published by the A.S.T.M. joint committee, previously referred to, will be valuable since no other thorough investigation has been made on this subject. Specifications commonly limit the sulphur content to 0.05 %.

Influence of phosphorus:- Read Article 688. The consensus of opinion is that phosphorus causes cold-shortness. Some evidence has been given to prove that up to 0.1 % it does not produce harmful brittleness. This question is also being investigated by the A.S.T.M. Joint Committee. It is quite generally agreed that additions of phosphorus increase the tensile strength and hardness and decrease the ductility, with an effect similar to that caused by the addition of carbon. For structural steels most specifications limit phosphorus, as they do sulphur, to about 0.05 %.

QUESTIONS

1. Describe the normal structure of wrought iron.

2. List the ultimate strength and proportional limit of wrought iron in tension and compression; also its modulus of elasticity.

3. How may wrought iron be distinguished from low carbon steel?

4. Why is the ordinary weld weaker than the original bar?

5. What is the proper method of making a weld?

6. What are the factors that influence the mechanical properties of steel?

7. How does carbon affect the tensile strength and hardness of steel?

8. What effect does carbon have on the modulus of elasticity of steel?

9. Explain why the drop-of-the-beam method cannot be used to determine the yield point in the case of high carbon steels.

10. What are the impurities in steel?

11. How does manganese effect the properties of steel?

12. What is meant by hot- or red-shortness? Can it be prevented?

13. Give the approximate strength of ordinary structural steel in tension and compression. What is its proportional limit? What is its modulus of elasticity? ~~Give similar values for wrought iron.~~

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Materials of Engineering Construction

Civil Engr 8 B. Assignment 24. Professor C.T. Wiskocil

EFFECTS OF HEAT TREATMENT OF STEEL

Effects of heating above the critical range:- Read Article 694. As will be noted in this article, there is a change in type and size of crystals when steel is heated above its critical temperature. When it is heated through the critical range, its previously existing structure is obliterated, or tends to become obliterated; and just above this range in temperature, the steel possesses the smallest crystalline structure which it is capable of assuming. The rate at which the structure is obliterated depends upon the temperature reached and the time the steel is kept at that temperature. Simultaneously with the obliteration of the old structure a new one begins to grow; the size of crystals increases, as a result both of the increase of temperature above the critical range and the duration of the high temperature; but more rapidly as a result of the increase.

The range in critical temperatures for straight carbon steels is given in the equilibrium diagram on page 591. The range in critical temperatures for various alloy steels is always supplied by the manufacturer. It should be noted that only eutectoid steels obtain their maximum refinement of grain size upon being heated through the Ac_1 temperature. As seen on

the equilibrium diagram, the critical range becomes a single temperature for eutectoid steels. In all cases complete refinement is obtained only when the constituents pass into a state of solid solution, assuming the form of austenite. Because of the lag or hysteresis effect the temperature should slightly exceed the upper critical temperature on the equilibrium diagram.

Effects of cooling from above the critical range:- Read Article 695. The size of the crystals in the austenite will largely determine the size of the final grain structure since the grain size does not change (decrease) with a decrease in temperature. For this reason the steel should be heated to as little above the critical range in temperature as considerations of time will allow. The rate of cooling through the critical range also affects the final structure. This change will be discussed under the subject of tempering.

Effect of grain size:- Read Article 696. With other conditions the same, the ductility, toughness and resistance to fatigue are increased with a decrease in grain size. In general, coarse grain size is indicative of inferior steel. Refinement of grain is effected by working steel as it cools to the Ar_1 temperature.

Annealing:- Read Article 697. Annealing of steel is practiced in order to accomplish three principal purposes. (a) to remove coarseness of grain and thereby secure a more desirable combination of toughness, strength, and ductility; (b) to relieve internal stresses set up in the cooling of castings and

the working of the steel in processes of drawing, forging, and rolling; and (c) to soften the steel to facilitate machining operations and meet certain physical requirements.

Annealing is generally applied to steel castings in order to refine their inherent coarse structure and thus to correct the lack of ductility and to increase the strength. Hot forged products are annealed to refine the relatively coarse structure which is caused by the high finishing temperature. Cold worked steel, such as cold drawn wire, must be annealed in order to increase or restore its ductility. The overstrain of wrought iron and steel (see Article 671 for wrought iron and 717 for steel) increases the yield point and ultimate strength but decreases the ductility. Iron and steel chains are frequently subjected to overstrain when links kink or heavy loads are suddenly applied. Chains in constant use should be annealed at regular intervals to relieve the internal strains. This practice is carried out in large plants where chains are used.

Annealing consists of three operations (1) heating the steel to some predetermined temperature, (2) keeping the steel at this temperature for a given length of time, and (3) cooling the steel according to some predetermined method to atmospheric temperature.

In order to soften steel for machining and to relieve internal strains it is not always necessary to heat the steel to the critical range. In the drawing of wire, in which the so called

"process" or "works" annealing is used and in the white annealing of cold rolled steel sheets the metal is not heated to the critical temperature. This treatment relieves the strain condition of the ferrite and restores the ductility. It does not, however, develop the maximum softness produced in true annealing.

For true annealing the steel must be heated past its critical range. Diagram 10 on page 627 gives the annealing temperatures recommended by various authorities. Draw the lines to represent the upper critical range in this diagram. The Ar_3 line extends from 0-900 to 3.5% carbon - 750° C., the Ar_{3-2} line extends from the latter point to 0.9 % carbon - 690° C. It will be seen that the recommended temperatures are well above the critical range.

The time required for annealing depends upon the size of the piece and may range from several hours to several days. The furnace should not be brought above annealing temperatures in order to accelerate the heating of the interior of large pieces. This treatment increases the grain size of the exterior, producing the harmful results previously mentioned.

There are three principal methods of cooling; furnace, insulated, and air cooling. Furnace cooling can be made the slowest and it will, therefore, give the best results in softness and ductility. In the process of insulated cooling when steel is taken from the furnace, it may be covered with an insulating material, such as sand, lime, or ashes. In air cooling, the steel is removed from the furnace and allowed to cool in air.

Effects of annealing on the mechanical properties of steel:- Read Article 698. In general annealing reduces the strength and hardness of steel, but increases its ductility and toughness. The actual quantitative changes are relatively unimportant.

Overheating and burning:- Read Article 699. Sometimes rivets are overheated or burnt. Such treatment can be easily detected by microscopic examination. The quality of burned steel is destroyed and it cannot be restored by heat treatment. It can be made into steel again only by being again melted and refined.

Theories of hardening steel:- Read Article 700. The retention theories are probably the most generally accepted even though they do not satisfactorily explain all of the observed facts. According to these theories hardened steel is in a state of unstable equilibrium and, therefore, is tending to assume a more stable form. That is, the iron has a constant tendency to return to the alpha form, and the carbon to revert to segregated cementite.

Essentials in hardening:- Read Article 701. Hardening results from heating the steel above its critical temperature and suddenly cooling it. Heating is done in various ways. For simple pieces, the ordinary blacksmith's forge is satisfactory. Electric or gas fired furnaces and baths are used when much hardening is to be done. Baths of molten lead or chlorides of calcium or potassium are commonly used for certain types of

work. But in all cases the steel is cooled by being plunged into a suitable liquid. This part of the process is called quenching.

The heating for hardening is the same as that for true annealing. Steel will not harden unless heated above its critical temperature. It should be thoroughly and uniformly heated at a slow rate to the lowest temperature that will give the desired results. This temperature should not be exceeded.

Methods of hardening. Read Article 702. Since the rate of cooling controls the hardening process, and since the cooling medium is the means of withdrawing heat from the steel, its selection is of importance. The various hardening media, in order of their hardening power, are listed in the text. The commercial use of these materials is also given. After water the chief quenching media are oils, all of which are slower than water. Combination methods of hardening, and their use and value, are discussed in the text.

Much skill is required on the part of the operator in quenching steel to prevent warping and cracking. Some of the difficulties are discussed on page 636 and methods for overcoming them are also given.

Steels containing less than 0.3 % carbon cannot be appreciably hardened by ordinary methods of heating and quenching because of the separation of ferrite from the solution during the process. This separation occurs even with the most rapid methods of cooling.

Effect of carbon on hardening: Read Article 703. The majority of the evidence on the effect of carbon does not agree with Figure 21 on page 636. Eutectoid steels posses the maximum hardening power. The difference in hardness between quenched and unquenched steels of this composition is greater than that of steels with other carbon contents. Steels with more carbon, hyper-eutectoid steels, may show greater hardness both before and after hardening because of the free cementite they contain or because the martensite has a higher carbon content. Hyper-eutectoid steels gain less in the hardening process than do eutectoid steels.

For the hardening process hyper-eutectoid steels are heated just above the Ac_{3-2-1} temperature. This, as can be seen in the equilibrium diagram, is the critical temperature for eutectoid steel. To convert both the pearlite and the free cementite in hyper-eutectoid steels into austenite it would be necessary to heat them to a point above the A_{cm} temperature. This would cause a coarsening in the grain size, an undesirable condition which is avoided by heating only to the Ac_{3-2-1} temperature. Steel quenched from the lower temperature is harder because it contains some free cementite, which is harder than martensite. When quenched at the higher temperature (Acm) it contains all martensite.

Microscopic structure of hardened steels:- Study Article 704. If high carbon steel is rapidly cooled, say in brine, a

considerable portion is left in the form of austenite. Austenite is rarely an ingredient of low carbon steels at normal temperatures except in the cases of some alloys. If the steel is cooled at a slower rate, the characteristic structure of martensite will be developed. See Figure 22 on page 637. Martensite is very hard and brittle. It is suitable for sharp-edged tools, but, on account of its brittleness, not for machine parts subjected to impact. With slower cooling the structure known as troostite is developed. This structure gives a steel that is slightly weaker but more ductile than martensite. Steel composed of troostite or a mixture of troostite and martensite is used for cutting tools and machine parts. With still slower cooling the steel assumes the structure known as sorbite. This is an intermediate structure between that of hardened and that of annealed steels. This structure produces steel of high strength with fair ductility; in other words a tough steel. Steel of Sorbitic structure is considered to be ideal for use in stress-carrying parts of machines. Annealing produces a structure made up of pearlite and ferrite for hypo-eutectoid steel, and of pearlite and cementite for hyper-eutectoid steels.

Tempering:- Read Article 705 to 709 inclusive. In the diagram in Figure 25, it should be noted that as the weight F decreases the end of the spring rises to the indicated positions; this action is analagous to the passing of the steel through the various transitional stages in the decomposition of austenite,

as a result of the release of fractional restraint.

Fully hardened steel is too brittle for use. It is tempered or drawn to regulate the hardness and brittleness, to toughen it, or to release the hardening strains. The process consists in reheating the steel to some temperature below the critical range, after it has been hardened. The tempering of edge tools is explained on page 643. The end of the piece to be tempered is heated just above the critical range and only the tip of this end is quenched; then the desired amount of heat, as judged by the change in color of the cleaned tip, is allowed to flow into the tip from the uncooled shaft. When the secondary heating has proceeded to the desired point the influx of heat is stopped by quenching the whole of the heated portion. Care should be taken to avoid a sharp line between the hardened and the unhardened portions of the steel. The tool should be kept in motion to prevent the development of this line during the quenching process. High carbon steels must not be kept at high temperatures any longer than necessary because the carbon is precipitated out under great heat in the form of graphite and thus the carbon content is reduced. This occurs only in the case of the presence of large amounts of carbon. Silicon also aids the precipitation of graphite.

Drawing is usually done in furnaces or baths maintained at the proper temperature. This temperature is determined by pyrometers; judging temperature by color of the steel is too uncertain for accurate work.

Maintaining steel at the drawing temperature for a considerable length of time will result in additional tempering.

The details given in Article 711 on the influence of hardening and tempering on the mechanical properties of steel cannot be remembered. Read this article and summarize in general terms the effect of this treatment on steel. Remember that tempering decreases the hardness and brittleness, and also the tensile strength and elastic limit. The ductility, as expressed by the percentage elongation and reduction in area, is increased by tempering.

Toughening consists in heating the steel to its critical range, quenching it and then drawing it back at a relatively high temperature so that little if any of the hardness due to the quenching remains. This practice is usually limited to steel with carbon contents ranging from .4 to .6 %, that is, to medium carbon steels. Toughening produces greater strength and ductility than annealing. In annealing, strength is sacrificed for ductility and softness. The quenching retains the fine grain size of austenite so as to insure the maximum strength of which the steel is capable. The drawing process relieves the quenching strains without increasing the grain size. Toughened steel is largely composed of sorbite, which gives the highest combination of strength and ductility.

Case hardening:- Read Article 710. Case hardening is essentially a special application of the cementation process.

When case hardened, the products are partially carburized so that the exterior case penetrates only a short distance below the surface and leaves the interior unchanged. It is employed to give a hard, wear-resisting surface to a tough core. Low carbon steels are used in this process.

QUESTIONS.

1. Explain why eutectoid steels only reach complete refinement in structure just above the Ac_1 temperature.

2. Describe changes in structure which occur on heating hypo-eutectoid steels through their critical range in temperature.

3. Why is steel annealed?

4. What is meant by "works" or "process" annealing?

5. What are the three steps in the process of true annealing?

6. What are the properties of burnt steel?

7. Will proper heat treatment restore the quality of steel that has been overheated or burnt?

8. How is steel hardened?

9. Why cannot low carbon steels (such as structural steel) be hardened by ordinary methods? Why is it necessary to specify the method of hardening of steel according to its use?

10. How does an increase in carbon affect the hardening power of steels?

11. How does the quenching medium affect the hardness of quenched steel? What are the principal quenching media?

12. What are the names given to the transition stages occurring in the process of the hardening of steel.

13. What is meant by the tempering or drawing of steel?

14. What is the structure of toughened steel? What are the advantages of toughening over annealing?

15. Why are low carbon steels used for case hardening?

UNIVERSITY OF CALIFORNIA EXTENSION DIVISION

Correspondence Courses

Materials of Engineering Construction

Civil Engr-8 B. Professor C.T. Wiskocil

Assignment 25

EFFECTS OF MECHANICAL WORK ON STEEL

Effect of hot work on the structure:- Read Article 712. If steel is worked at its critical range by any of the methods previously discussed the grain structure will be refined. After the critical range has been passed additional work will not cause any change in size of the grains. The refinement of grain structure in a steel casting due to forging is shown in Figures 11 and 12 on page 628. By the time the steel has been worked, its temperature should be near the lower critical value so that the grain structure will not be changed by heat that may remain in the piece. No changes will occur below the critical range.

Effects of hot work on the properties:- Read Article 713. Since hot work during the cooling of steel through the critical range in temperature refines the grain size it is to be expected that the physical properties of the steel will be improved. Certain examples are given in the text. Large shafts must be forged with heavy blows so that the effect of the mechanical work will penetrate the material, or they should be made hollow so that better metal will be assured.

Effects of cold working:- Read Articles 714 to 717 inclusive. Steel is ordinarily rolled at a red heat, and through this process the strength and ductility are increased, because of the

refinement in grain size, as previously noted. If steel is ~~brought~~ rolled to its final size at temperatures below its critical range, it is called cold-rolled steel. Working the steel at this temperature increases its tensile strength and elastic limit but decreases its ductility. The grains are distorted and do not reduce in size as they do at temperatures within the critical range. The distortion of the grains or crystals produces internal stresses that raise the strength and elastic limit. Cold drawing of rods and wires has the same effect as cold rolling of steel. Cold rolled steel is used for shafting because the process leaves a smooth surface and true dimensions so that machining is not necessary. If machining is done, such as cutting keyways or holes, it is liable to distort or warp the shaft due to the redistribution of the stresses caused by the cold working. Most steel wire is cold drawn and cold drawn shafting may be obtained up to 3" in diameter.

The effect of cold working can be removed by annealing. From previous discussions on the changes in grain structure caused by annealing the refinement of structure and release of internal stresses in cold worked steel can be readily understood. This change is well illustrated in Figure 39 on page 659.

Grain growth in steel:- Read Article 718. Cold working may cause the growth or enlargement of crystals in the case of certain pure metals but not in the case of commercial iron and steel. Overheating, that is heating over the critical temperature, will cause increase or coarseness in the structure of steel.

Stead's brittleness is a condition caused by heating from 650° to 750°C for long periods of time. It occurs in low carbon steel and causes large crystallization with a decrease in ductility. It is not often encountered because the necessary conditions rarely occur in practice. Where it does occur, othe original grain structure can be regained by proper annealing.

Influence of form on properties of steel:- Read Articles 719 to 723 inclusive. The form of the piece affects both the distribution of stress and the elongation under tension. These considerations are of most importance in design and investigation. It is natural to expect that where steel is confined, it will have greater strength and elastic properties, as discussed in Article 723. These matters, however, are relatively unimportant in a course in Materials.

Wire rope:- Read Articles 724 and 725. The properties of steel wire are given in Article 724. Methods of manufacture have been previously discussed. Plow-steel is one of the strongest materials used in the construction of wire rope. The name originated in England where it was applied to a strong grade of crucible steel wire which was used in the construction of strong ropes employed to pull gangs of plows. At present it is used to designate a high grade of open hearth steel; and in wire rope made of plow-steel, the tensile strength of the wire is about 250,000 lb. per sq. in. The proportional limit of plow steel is about 70% of its ultimate strength while its ductility is very low; the average

percentage elongation is 5%. While plow steel is an unsatisfactory name it has been associated with the trade for such a long time that it has come to have a fairly definite meaning.

Lang-lay rope is defined in Article 725. The difference between this type of rope and ordinary rope should be remembered. In regular lay rope, the wires of the strands are twisted in one direction and the strands laid into the rope in the opposite direction. Most of the rope used in America is regular lay rope; and rope of this type has become standard for most work. In Lang-lay rope both the wires in the strands and the strands are in the same direction. It is more easily untwisted than regular lay rope and it is also more difficult to splice. It is well adapted to external wear and grip action. Its use is rather limited compared to that of regular lay rope.

Most rope is made right lay, which means that it is twisted to the right, like the threads of a right hand screw of long pitch. The majority of oil-well drilling ropes are made left lay. The construction is specified by giving the number of strands in the rope and the number of wires in each strand. A 6 by 19 rope is one having 6 strands of 19 wires each. The strands are laid around a hemp or manila center to form the complete rope. The hemp or fiber center holds the lubricant and affords a bedding for the strands The life of a rope depends on a number of factors: the character of the metal used, the construction of the rope, the diameter of drums, sheaves, and pulleys over which it operates;

and to a great extent how it is lubricated. When intended for heavy wear the hemp center should be saturated with a suitable lubricant. The lubricant reduces friction between the component parts of the rope and prevents corrosion.

The diameter of a rope is ~~usually taken as~~ the diameter of its cross-section of a circle just enclosing ~~the rope~~. In a 1 1/2 inch rope the smallest cross-sectional dimension may be as little as 1 3/8 inches. Frequently this latter measurement is incorrectly ~~sometimes~~ taken as the diameter.

There are various classes of wire rope. Tiller rope is the most flexible. It is used motly for boat tillers. Guy rope is used for guying steel stacks, derrick masts, and gin poles, and for similar purposes where there is static load without impact. It is sometimes used also in hauling where the ropes are not bent over sheaves. The wires are usually galvanized. Hoisting rope of crucible steel is commonly used for mine hoists, elevators, conveyors and derricks. Hoisting rope of plow steel is used in heavy work, as for instance in locomotive and wrecking cranes. Extra-flexible rope of plow steel is used on steam-shovel gear and in cases where it is wound around small diameter drums.

The ratio of strength of rope to average strength of wires is usually called the efficiency of the rope. This value of is usually about 85%. The strength of the rope depends upon the material and method of its construction upon its diameter.

THE STRENGTH AND ELASTIC PROPERTIES OF METALS AT ELEVATED TEMPERATURES

Read Articles 809 to 820 inclusive. The uses of metals under conditions of high temperature are listed in Article 809. In spite of the importance of the subject there has been little systematic research undertaken. In a general way, the diagram in Figure 6 on page 763 gives the results of investigations so far completed. Steel reaches a maximum tensile strength about 600° Fahrenheit. and for temperatures over that value the strength decreases quite uniformly to about 1600° F. at which temperature it looses practically all its strength. It is possible that different steels will exhibit different points of maximum strength but in general the figures given represent average conditions. The ductility decreases until about 600° F. is reached and for higher temperatures it continually increases. The proportional limit and modulus of elasticity show a gradual decrease with the increase over atmospheric temperature. Cast iron and wrought iron are similar to steel in their reaction to elevated temperatures. Brass and aluminum show a uniform decrease in tensile strength as the temperature is increased.

When steel is used at elevated temperatures as the fire-box of a boiler or the stays in an open hearth shed furnace it is under stress; investigations, therefore, should be made with long-continued or permanent loads. Up to this time no such studies have been undertaken.

Welding of steel:- This subject is not discussed in the text. The welding of wrought iron was referred to in Article 674 on page 606. Steel welding, which is known as welding at plastic heats, is successfully practiced with soft steel, but hard steel (high carbon) can be welded by this method only by an experienced operator. Cast iron cannot be welded by plastic welding. Plastic welding is done in a forge fire or by electricity. The parts to be joined are brought to a temperature a little below fusion and pressed or hammered together. When electricity is used the method is called resistance or spot welding. Pieces that do not have to transmit heavy stresses are fastened together by this method. Pieces which are later to be more thoroughly joined are often tacked together by spot welding. Spot welding is often well adapted to certain kinds of manufacturing operations, such as the making of wire fabric for concrete reinforcement, and of wire reinforcement coils for concrete pipe, chain manufacture, and welding valve stems to valve heads. The temperature can be closely controlled in this process.

There are three principal methods of fusion or autogenous welding. The first is oxyacetylene welding in which the metal is actually fused by high temperatures resulting from the burning of the gas, usually acetylene, in a stream of pure oxygen. The two gases are fed through a blow pipe torch and ignited at the tip. The high temperature, approximately 5000 degrees Fahrenheit, fuses a narrow strip of metal at the joint and unites the parts. A narrow steel or iron rod is melted in the joint to supply additional

metal. Most metals can be welded by this process.

In this operation, the oxyacetylene torch is used as a cutting tool. For this purpose the oxygen is supplied in excess and the temperature is increased so that the steel is burned. It is used in cutting off lugs, gates and risers from steel castings where the cold-saw was previously used. The torch has brought about large savings in this operation. It is also used to cut up scrap and wreckage of various kinds. Oxyacetylene welding is applicable to thin plates of metal. It produces a coarse structure since it is essentially a casting. A common weakness in this method is that the metal at the joint is not thoroughly welded at the middle of the thickness of the plates. Joints of this kind can be made so that the average efficiency is about 80% but as usually made under ordinary conditions by the average workman the efficiency approaches nearer to 50%. Torch welding is widely used in repair work in which cast as well as rolled metals are to be repaired, and is the method in most general use.

A second method of fusion welding is the thermit methods. The necessary temperature is secured by igniting a mixture of iron oxide and aluminum. The materials are ignited in a crucible and where they reach a temperature of approximately 4500 degrees F., the hot metal is poured into the joint to be repaired. It forms a casting and is therefore adapted to the repair of heavy sections such as locomotive and heavy engine or machines frames. Repairs by this method can be readily made in the field.

A fusion weld can also be made by the use of an electric arc. The arc is drawn between the metal and an electrode of steel or iron which is held in the hand of the operator. The metal to fill the joint is supplied partly by the metal to be repaired and partly by the electrode, both of which are fused by the temperature of the arc. This method cannot be used in the field unless electric current is available. It is an excellent shop method. If alternating current is supplied a motor-generator set or rotary converter is necessary tp produce direct current. As reported in Bulletin 179 United States Bureau of Standards on ELECTRIC-ARC WELDING OF STEEL, the mechanical properties, as measured by the tension test and by microscopic examination, show that arc-fused metal is an inferior grade. The ductility is particularly low. With careful manipulation and annealing, however, very satisfactory welding can be done by this method.

QUESTIONS

1. In what way does hot-work affect the structure and properties of steel?

2. What is meant by cold-working? How does it affect the properties of the steel?

3. Is it possible to restore the original ductility to cold- drawn steel wire?

4. What is plow steel? What is its approximate tensile strength, proportional limit, percentage elongation and modulus of elasticity?

5. What is a Lang lay rope?

6. What is a left lay rope and what is its principal use?

7. What factors determine the life of wire rope?

8. Define efficiency as applied to wire rope. What is the average efficiency?

9. Would the strength of steel be affected if it were used at a temperature of 500 degrees F.?

10. What are the two principal types of welding?

11. What welding process would you advise for the repair of a broken locomotive frame? For a cracked automobile fender? For filling blow holes in a defective steel casting? For repairing a wrought iron tie rod? For replacing a broken tooth in a cast iron gear?

UNIVERSITY OF CALIFORNIA EXTENSION DIVISION

Correspondence Courses

Materials of Engineering Construction

Civil Engr-8 B. Professor C.T. Wiskocil

Assignment 26

ALLOY STEELS

Introduction:- Read Article 728. This may be said to be the age of alloy steel. It has been demonstrated that the development and manufacture of airplanes, automobiles, tractors, artillery, armour plate and cutting tools would have been impossible without alloy steels. Langley's original airplane, which antedated the successful machines of the Wright brothers, could not be successfully operated because of the heavy and inadequate power plant. It was recently equipped with a modern motor and it flew perfectly. Early automobiles, commonly known as horseless-carriages at the time they were first introduced, were cumbersome, expensive devices compared with the automobile of today. The development of automotive machinery is thus due to alloy steel. During the past fifteen years and especially during the War many problems have been encountered that could not be successfully met with ordinary carbon steels. The builders of the lowest priced automobile in the world today, which contains the highest percentage of relatively expensive alloy steels, acknowledge that it is the use of these alloy steels which has made their product possible.

High grade steels, other than structural grade and machine steel, reach the user in a condition in which the properties are

still to be developed. In the case of carbon steels the application and removal of heat to bring out or develop the properties inherent in the steel were thoroughly discussed. Alloy steels also require heat treatment to produce the physical properties which they are capable of developing.

Many different alloy steels have been developed but relatively few have gained commercial importance. Probably the first commercial alloy steel was the self-hardening tungsten tool steel developed by Mushet in 1868. About fifteen years later a chrome steel was put into use for the manufacture of projectiles. Then in 1882 the well-known manganese steel was discovered by Hadfield. The development of nickel and the other commercial alloy steels followed the discovery of manganese steel.

The definition of alloy steel as given by Hibbard is similar to that given in the text. "Alloy steel is steel that contains one or more elements other than carbon in sufficient proportion to modify or improve substantially and positively some of its useful properties".

Ternary Alloys

A simple form of alloy steel is that which is sometimes called (as in the text) ternary steel. It is one which contains one alloying element besides carbon and iron. The term ternary is used because of the fact that the steel is made up of three principal constituents, while the designation simple alloy is

logical, because in steel of this type, only one alloying element is added to carbon steel. The tungsten and manganese steels previously mentioned are simple alloy steels.

As has been noted in the discussion on manufacture of steel, in all steels various elements are added for curative purposes during the making process. Manganese in quantities less than 1 1/2 % was added to prevent red-shortness, aluminum is added to quiet the molten steel before pouring, and other elements such as silicon, titanium and vanadium are added in small quantities for similar reasons. The introduction of these alloying elements does not bring steel into the strict alloy steel class. It results merely in what is called alloy-treated steel.

Alloy steels are usually heat treated because heat treatment adds to the superior qualities which have been gained by the use of alloys. Certain structural steels when made into large units such as rails and members for bridges are used without heat treatment. Their superior properties are due solely to the presence of the alloying element - usually nickel. Where practical, structural steel products are heat treated. Structural steel is used for stationary and moving parts of vehicles, machines, ships, and armor plate, as well as for bridges and buildings. Alloy steels for cutting tools and electrical purposes are placed in separate classes and furthermore they are usually treated with different alloying elements.

Sometimes alloy steels are heat treated before they are machined. This process is very difficult if the elastic limit is

in excess of 100,000 lb. per sq. in. It is claimed that chrome-vanadium steel can be commercially machined even up to such strength as represented by 150,000 lb. per sq. in. elastic limit, Chrome-molybdenum steel is even more easily machined than Chrome-vanadium. No commercial alloy steels exceed 100,000 lb. per sq. in. in elastic limit strength in the normal state.

Alloy steels are made by pneumatic, open hearth, crucible, and electric processes. The largest tonnages are made by open hearth and electric methods. They are usually alloys of nickel, chromium and vanadium.

Nickel Steel:- Read Article 792. Nickel steel was used for the first time about 1888. It aggregates a large tonnage at the present time but the field is being reduced by the cheaper and in some ways better chrome-nickel steels. Most of the straight nickel steels are made by open hearth methods. Additions of less than 2% nickel are not worth the extra cost. Useful nickel steels range from about 2 to 46% nickel. This is a wider range than has been found for any other alloying element. Untreated nickel steel has higher elastic limit and ultimate strength than similar carbon steel without nickel, but practically the same ductility. Heat treatment increases the strength of nickel steel, both elastic limit and ultimate, but it also decreases the ductility.

Nickel may be added to the steel at any time just so that it has opportunity to become thoroughly diffused throughout the melt before it is poured. It is usually added to the bath just

before it is tapped. It is not added for curative purposes; it is preeminently a strength giving element. Unfortunately nickel steel is subject to certain defects such as seams and surface marks, which limit its use.

Ordinary nickel steel contains from 3 to 4 % nickel. When the percentage of nickel is not specified in an order steel containing about 3.25 % is furnished since this percentage produces the best properties for most structural purposes. This type of nickel steel is well adapted to service conditions that are too severe for ordinary carbon steel, such as in certain kinds of bridges, gun forgings, engine and automobile parts, and large dynamos.

In the range used in ordinary nickel steel (2 to 4%) each addition of 1% nickel increases the tensile strength about 6,000 lb. per sq. in. over carbon steel, without affecting the ductility. This increase occurs through the additions of nickel, without heat treatment. The use of nickel saves some weight, which is a factor in the construction of long span bridges such as the Quebec bridge in which untreated nickel steel was used. Steel having about 3.5% nickel is good case hardening stock.

With the addition of from 5 to 8 % nickel the metal becomes very hard and is difficult to work in both the hot and cold conditions. Its principal use is for the manufacture of thin armor plates which are used for protecting field artillery from rifle fire.

Steels containing about 10 % nickel cannot be hardened by quenching.

In 1914 a steel containing 13% nickel and .55% carbon was discovered which had a yield point of about 134,000 and an ultimate tensile strength of 195,000 lb. per sq. in. This alloy of nickel is thought to be the strongest in the entire series of nickel steels. It is very hard. It cannot be machined or drilled. Its elongation is about 12 %. Its commercial use is very limited; it is only made into shafting to replace shafts made of other steels that could not withstand the particular service conditions.

Steels containing about 22% nickel have high rust resisting qualities. Steels having from 24 to 32% nickel are used for electric resistance, in such articles as electric iron, toasters, and other household heaters.

Invar steel, which contains 36% nickel, is mentioned in the text. Not more than a few hundred pounds a year are used; yet in certain industries it is important. Its principal uses are listed in the text. Some invar tapes have been made with coefficients of thermal expansion as low as .0000008 per degree centigrade. This means a change of 0.05 inches per mile for one degree centigrade change in temperature. Some invar steels have been found to have negative coefficients; that is they actually contract when heated.

Platenite is also mentioned in the text. It contains 46% nickel and .15% carbon. It was at one time more used than it is now, principally for wires which lead into electric lamp bulbs.

It was a substitute for platinum. Other alloys are now replacing platenite for the purpose mentioned.

There are other alloys of nickel but they are of scientific interest only.

Manganese steel:- Read Article 730. Commercial manganese steel contains from 11 to 14% manganese and from 1.0 to 1.3 % carbon. Most of the manganese steel produced is made into castings. The field for manganese steel is not very large and there are relatively few concerns making it. About six companies in United States supply practically all that is made.

Manganese steel is made by the pneumatic, open hearth, and electric processes. In the process of manufacture, ferromanganese is added to the decarburized metal. This supplies all of the manganese and practically all of the carbon, in the finished metal. Manganese steel cannot be successfully made from manganese steel scrap. On the whole it is more difficult to make and cast than carbon steel. At the present time it cannot be commercially machined. It is used for jaws of rock crushers, for rails, frogs and crossings for railroad work, and also for burglar-proof safes. These safes are made of a laminated construction having alternate layers of hard and soft steel thus making it difficult for a drill to penetrate. Manganese steel, as well as all other kinds, however, can be readily cut with an oxyacetylene flame. Manganese steel has a low yield point. Under many field conditions it peens-out or flows under repeated blows. This makes

it unsatisfactory for uses for which its high abrasive resistance would otherwise make it preeminently successful. Manganese steel for buckets in gold dredgers is being replaced by other alloys with higher elastic limits. The breaking of a bucket line causes expensive delays and a reliable product is required. It is more difficult to obtain uniform material and finished castings in manganese steel than in other types of alloy steels. The principal demand for hot-rolled manganese steel is for use as railroad rails.

Chrome steels;- Read Article 731. Steels alloyed with chromium have great strength and hardness. Chrome steels are cast, rolled and forged just as carbon steels are. They are rarely used in the untreated condition. Chrome steels have been used for stamp shoes in pulverizing gold and silver ores, and for safes. Some chrome-steel is also made into files and balls and rollers for bearings. Simple chrome steel was one of the first alloy steels commercially used.

Chromium, however, is usually alloyed with other elements to form quarternary alloys.

Quartenary Alloys

Tungsten steel:- Read Article 732. Simple tungsten steel is now becoming obsolete. It was important at one time and formed an important stage in the development of high-speed tool steels. Mushet's air-hardening steel, while it contained 6% tungsten and 2 % manganese - the latter added to give it the

self hardening property - was usually classed as a simple tungsten steel.

Vanadium Steel:- Read Article 733. Vanadium adds great strength to steel and makes it free from flaws and seams. It is used in high speed steels. It is not used much as a simple alloy but usually is combined with chromium. Chrom-vanadium steels are used principally for locomotive forgings, automobile springs and axles and gun forgings.

Silicon steels:- Read Article 734. Silicon is an ingredient of practically all steels. It is added to tool and structural steels to promote soundness, and is added just before the metal is teemed, and should preferably be in a molten state. The principal use for silicon steel is in the manufacture of leaf springs for automobiles.

Chrome-nickel steel: Ores found near Mayari, Cuba, yield a natural chrome-nickel steel. Mayari steel, as this product is called, has been found to have excellent qualities for certain purposes; but it is generally inferior to synthetic chrome-nickel steels. This type of alloy steel is widely used in the manufacture of automobile parts and for armor plate and armor piercing projectiles. Chrome-nickel shafts and gears have excellent wearing qualities.

Chrome-vanadium steel:- Read Article 736. Chrome-vanadium steels are made in the open hearth furnace and the alloying elements are added just before casting. Chrome-vanadium steels slightly

surpass chrome-nickel steels in physical properties. Most of the output goes into the manufacture of automobiles. Vanadium is a strong deoxidizer while nickel is not. Vanadium steels are, therefore, more free from surface imperfections such as seams than are steels which contain nickel.

Molybdenum steel:- Molybdenum is added in the form of ferro-molybdenum or calcium molybdate. The final molybdenum content of the present commercial molybdenum steels is less than 1%. Since the War molybdenum steels have become commercially important. They will probably soon replace chrome-nickel and chrome-vanadium steels which are now so generally used in automobile construction. During 1921 the Studebaker Corporation used over 2,000 tons of molybdenum steels. The high grade Willis Sainte-Clair automobile is made largely of molybdenum steel. Chrome-molybdenum steel is more easily machined than the nickel and vanadium alloys of chromium.

During the War molybdenum was used as a substitute for tungsten in the manufacture of tool steel (high-speed). Its largest use was for light armor plate, and vital parts of airplane motors and automotive vehicles.

For its high strength chrome-molybdenum steels have great ductility. Automobile parts such as axles and shafts, made of molybdenum steel can be distorted and twisted without rupture. Heat treated chrome-molybdenum steel has the following approximate strengths; 140,000 lb. per sq. in. elastic limit, 150,000 lb.

per sq. in. ultimate tensile strength, 18% elongation and 60% reduction in area.

High-speed steels:- The presence of tungsten or molybdenum in steel affects its critical temperature. With proper heat treatment steels containing these alloys retain their hardness and consequently a cutting edge at a red heat. One form of heat treatment is the heating of the steel to incipient fusion, and quenching in oil. Tungsten, molybdenum, cobalt and vanadium are those alloys used in the manufacture of high-speed steels, which are usually made by the crucible or electric process.

Stellite, a competitor of high-speed steels, is not a steel, being composed of approximately 60% cobalt, 11% chromium, 23% molybdenum, the remainder being manganese, iron, carbon, etc.

QUESTIONS

1. What is an alloy steel?

2. What was the first commercial alloy steel and what was it used for?

3. What is a ternary alloy steel? Name several.

4. What processes are used in the manufacture of alloy steels?

5. What is invar steel? Give its composition and principal uses.

6. What is the percentage of nickel in simple nickel steel used for ordinary structural purposes? Why is this steel better than carbon steel?

7. What is the range in manganese in commercial manganese steels? What are the outstanding properties of this steel? What are some of its uses?

8. What is Mayari steel?

9. What are the principal alloy steels used in the automobile industry?

10. What is the advantage of vanadium over nickel in quarternary alloys using chromium?

11. What are the particular advantages of chrome-molybdenum steels? What are the uses for this steel?

12. What is meant by a high-speed steel?

13. Explain why high speed steels retain their hardness at high temperatures.

UNIVERSITY OF CALIFORNIA EXTENSION DIVISION

Correspondence Courses

Materials of Engineering Construction

Assignment 27

Civil Engr-8B Professor C. T. Wiskocil

CAST IRON

Importance of cast iron: Read Article 738, which gives the principal uses for cast iron. In building construction it is not as widely used as steel; its greatest field of use is in machine construction. As indicated in this article, however, other metals must also be frequently used in machine construction because cast iron does not adequately supply the necessary qualities. These competing materials are malleable cast iron, cast steel, and cast brasses, bronzes, and other alloys.

Cast iron has a comparatively coarse crystalline structure, as shown in Figure 4 on page 697. It is readily cast into useful shapes and is easily machined, but is lacks toughness and ductility. It has considerable hardness but cannot be deformed by forging without being broken. Its constitution is very complex, and it is subject to much variation resulting from relatively minor changes in the details of manufacturing.

Manufacture of cast iron: Study Articles 739 to 743 inclusive. When pig iron is remelted and cast into final form it is called cast iron. See the definitions previously given on page 586. A limited amount of iron is cast directly from the molten state as it comes from the blast furnace. Ingot molds are made in this way.

Most cast iron is made, however, by a mixture of scrap iron with pig iron. The reasons for remelting pig iron and mixing different grades of iron and scrap are given in Article 739. Most cast iron is made in this manner; either the cupola or air furnace is used.

The materials used in the manufacture of cast iron are described breifly in Article 740. The major portion of the charge in the furnace usually consists of foundry pig iron. The amounts of the constituents usually specified are listed on page 540, Article 582. Most foundry pig is bought on the basis of its analysis. Bessemer pig, ferro-silicon, and other materials mentioned in the text are used to bring the final composition of the cast iron to desired limits. Some classes of castings are made without scrap while others contain as much as 40% scrap. The term "scrap" includes, besides worn and discarded iron castings, defective castings, gates, sprunes, risers, and other pieces of iron reclaimed in cleaning up castings.

The flux is used to form a slag and carry off the impurities and non-metallic residue. Since the amount of impurities is small the amount of flux required is also small, being ordinarily about 1% of the weight of the iron charge. Calcium carbonate usually in the form of limestone is used as a flux but marble, dolomite, and oyster shells are sometimes added to the charge.

The fuel is used to melt the iron. Coke is most commonly employed but mixtures of coke and anthracite coal are sometimes used in cupolas. Gas and bituminous coal are used in the air furnaces.

The fuel requirements are determined by the type of castings to be made, thin castings requiring a more fluid and therefore a hotter metal than that necessary for large thick castings.

A typical cupola furnace is shown in Figure 1 on page 689. It is essentially a small blast furnace. Only a light blast is used and no attempt is made to attain reducing conditions required in the regular blast furnace. The only function of the cupola is to melt the charge. The proportion of fuel to iron is usually about 20%.

The usual type of air furnace is illustrated in Figure 2 on page 690. The heat from the fuel passes over the bath and is reflected by the roof of the furnace. For this reason it is sometimes called a reverberatory furnace. An air furnace resembles the puddling furnace used in the manufacture of wrought iron. The copula is used for melting iron for gray iron castings while the air furnace is used in the production of white cast iron for malleable cast iron and for cast irons of special compositions.

The open-hearth furnace is used to a limited extent in the manufacture of cast iron. It is more economical in the consumption of fuel than the air furnace but to be used to advantage it must be operated continuously. This requires a large floor space for molding and a large output of cast iron.

Study Article 743 on the comparison of the cupola and the air furnace. The air furnace uses about twice as much fuel as the

cupola but it produces purer metal and in larger quantities. Both types of furnace are widely used.

Molding of cast iron: Read Articles 744 to 749 inclusive. Only in the case of the chilled castings is the quality of the metal affected by the mold. Under normal conditions of cooling the quality of the metal depends upon its composition.

The molding of cast iron is of importance to the engineer and machine designer. The pattern must be so designed that it can be removed from the sand and leave the mold intact and the shape of the casting must be so designed that dangerous shrinkage stresses are not set up when the casting cools. The three methods - green-sand, dry-sand, and loam molding - are all explained in the text.

Patterns are divided into two classes. In the first class, which includes most of the castings, the patterns are solid. In the other class the hollow part is formed by a core which is inserted in the mold after the pattern is removed. The materials from which patterns and cores are made are described in the text

The use of chills is described in Article 748. They are used to produce a hard wearing surface on such castings as rolls and car wheels. Chilled-iron car wheels are cast with a chill against the tread and the inside of the flange, the remainder being in sand. The composition of the metal is such that under the imposed conditions the metal against the chill will show white iron to a depth of about 7/8 of an inch, the remainder of the wheel being graphitized or gray. So as to relieve the severe cooling stresses the wheels

are stripped from the mold while still red hot and placed in a soaking pit where they are allowed to cool slowly. A maximum temperature of about 725 degrees Centigrade has been found to be satisfactory for this annealing process. If the temperature is higher an undersirable formation of graphite occurs within the white tread. The effect of chills on the structure of cast iron is shown in Figure 3 on page 695.

The cleaning of castings is described in Article 749. The three methods are rattling, pickling, and sand blasting. Rattling is satisfactory only in the case of the simplest castings. Pickling is in more general use; and sand blasting is most convenient for large castings. Often the sand blast is followed by pickling. In all these methods, the final cleaning operation is the smoothing of irregularities such as are left where gates and fins have been broken off. This is done with a cold chisel, with a pneumatic chipping tool, or an emery wheel.

Composition and constitution of cast iron: Read Articles 750 to 758 inclusive. Cast iron is a complex alloy composed of six important elements - iron, carbon, silicon, phosphorus, sulphur, and manganese; other unimportant elements are often present. The most important element is carbon because of its pronounced effect on the strength of cast iron. It occurs free as graphite and in the combined form as cementite (Fe_3C) which is sometimes called iron carbide or combined carbon. The importance of the other

elements is due to their influence upon the carbon. There are three distinct classes of cast iron, depending upon the state in which the carbon occurs. In gray cast iron the carbon occurs chiefly as free carbon in graphite flakes. In white cast iron it is principally in the combined form, while in mottled cast iron there is a mixture of particles of gray and white iron. A product of the air furnace or cupola containing from 20 to 50% steel scrap is known by the misleading trade name of semi-steel (see definition on page 588). The metal is actually a fine grained cast iron. It is much stronger than ordinary cast iron but it is not steel. It is used where a strong, close grained metal is required, as in hydraulic cylinders; and in parts requiring strength and shock resisting ability, as in shear and punch frames.

The composition and the rate of cooling, through the range of solidification and immediately below that temperature determine whether a given mass of molten cast iron will be gray, white or mottled. The more rapid the cooling the less the graphitization (white cast iron, for instance, made by chilling the molten iron).

Carbon in cast iron is discussed in detail in Article 751. The range in carbon content for commercial cast irons was given on the equilibrium diagram for iron and carbon. The strength and other properties of the casting are dependent upon the form in which the carbon occurs. Figure 5 (after Howe) on page 699, shows the effect of graphite and combined carbon. The important features in

this diagram are: the names of the cast irons in the upper part of the diagram; the tenacity, ductility, and hardness of the whole with ordinates and abscissaes in the central portion; and all of the lower part of the diagram. In this latter portion, note that mottled cast iron is not alluded to except to state that it is harder. Irons of this type have no special adaptation and their production is not intentional.

Graphitization, that is the decomposition of the combined carbon to form graphite, is facilitated by increased carbon or silicon content and by slow cooling. Graphitization is retarded by sulphur, excess manganese, and rapid cooling. This is a brief summary of Article 751. The effect of the various elements will be discussed separately in detail.

Silicon in cast iron is discussed in Article 752. It ranks below iron and carbon in its importance as a constituent. The amount of silicon in cast iron can be controlled. It acts principally as a precipitant of graphite, causing a maximum precipitation when about a quantity of 3%. Below 3% it will aid in the production of gray iron, but over 3% causes iron silicide, which results in a hard brittle metal. Small amounts decrease shrinkage and minimize blowholes.

The effects of sulphur are discussed in Article 753. As in the case of silicon the amount of sulphur in the cast iron can be controlled during the manufacturing process. Sulphur has a decided

effect upon the properties of cast iron. It prevents graphitization and produces hard, brittle iron. Specifications limit the sulphur content to 0.1% and some even to as little as 0.50%. Sulphur causes red-shortness and blow-holes. It is an undesirable element. The effect of sulphur can be neutralized by silicon and manganese, About 15 parts of silicon or two parts of manganese are required to neutralize one part of sulphur.

In the best grades of gray iron the phosphorus content is limited to 0.5%. High phosphorus causes cold-shortness. But when fluidity is important, as in the pouring of thin castings which must have a good impression of the mold, and where toughness is not required, about 1.0% phosphorus is used. The amount of phosphorus cannot be controlled, it is determined by the amounts present in the materials from which the cast iron is made.

When manganese is present in small amounts it combines with the sulphur to form manganese sulphide and tends to decrease the hardness and brittleness of the iron; but in greater quantities it causes increased hardness.

The other elements that may be present in cast iron are of importance to the iron manufacturer but not to the student of a general course in Materials. Article 758 with Table 1 can be omitted since the approximate allowable proportions of the various elements have already been discussed and the student therefore has a general idea of the composition of good cast iron.

Read Article 757 on defects and remember what the principal defects are and how they are caused.

PROPERTIES OF CAST IRON

Shrinkage: Read Article 759. The pattern maker must make allowance for shrinkage and the designer and the iron founder must consider this phenomenon because of the induced stresses and consequent danger of checking. It is usually assumed that shrinkage is about 1/8 of an inch per foot. It is quite variable, the chief factors which influence it being the presence of silicon, the rate of cooling, and size of the cross-section of the casting.

Hardness: Read Article 760. Hardness is the term generally used to designate that quality which has to do with the resistance of a metal to cutting or machining, or to wearing or abrasion. As shown in Figure 5 on page 699, the hardness increases directly with the amount of combined carbon. This may be due to the hardness of the cementite itself and to the decrease in graphite which acts as a lubricant to the cutting tool. Hardness is measured by the drill test and the ball-indentation test. Both are empirical. Review Article 129 on page 127.

Tensile strength: Article 761 is relatively unimportant. Tensile strength is important but in a direct test it is difficult to determine. For average gray iron the ultimate tensile strength is about 20,000 lb. per sq. in. Omit the tables on pages 707 and 708. Remember the typical stress-deformation curves on page 709.

They show that cast iron has no proportional limit. It is important to note that cast iron is weakest in tension. In torsion or combined stress the piece will fail in tension and its strength will be limited by the tensile strength of the metal.

Compressive strength: Read Article 763. The average compressive strength of ordinary gray cast iron at the proportional limit, or yield point, as it should more properly be called, is about 30,000 lb. per sq. in. The ultimate strength is about 70,000 lb. per sq. in. Figure 11 on page 710 represents a typical stress-deformation curve.

Transverse strength: Read Article 764. The arbitration bar is described in this article. It is the most important test specimen of cast iron. Under standard conditions an arbitration bar of average gray cast iron will give a modulus of rupture of about 45,000 lb. per sq. in. This test gives a valuable criterion of the quality of the metal. It is necessary that the conditions for the test be standardized, because the size of specimen and its method of preparation affect its strength. The removal of the skin by machining decreases the strength, while tumbling hardens the skin and increases the strength.

The A.S.T.M. minimum requirements for the modulus of rupture in the test of the regulation arbitration bar are 39,000, 45,000 and 50,000 lb. per sq. in., respectively, for light, medium, and heavy castings. The minimum deflection is 1/10 of an inch.

Modulus of elasticity: Read Article 765. The modulus of elasticity of cast iron is quite variable; 15,000,000 lb. per sq. in. may be taken as the average.

Articles 766 to 771 inclusive are relatively unimportant. Remember that the shearing strength of cast iron is greater than its tensile strength. When subjected to torsion cast iron fails in tension which in this case is a secondary stress.

Ductility: The ductility of cast iron is very slight.

MALLEABLE CAST IRON

Introduction: Read Articles 772 and 773 on the nature and importance of malleable cast iron. Malleable cast iron is white cast iron, which, after it has been cast into final form, is rendered malleable by an annealing process. Malleable cast iron can be cast into complicated forms, and after casting, its toughness, ductility, and strength can be materially increased. It is used principally for implements, machinery, and rolling stock. For these purposes it is surpassed only be steel castings and forgings. It is also used in the manufacture of articles whose form is too complicated for economical forging.

Manufacture: Read Articles 774 to 776 inclusive. Malleable cast iron is made from foundry pig iron, scrap from the casting floor, steel scrap, and to a limited extent annealed malleable iron scrap. The cupola, air furnace, and openhearth furnace methods are those chiefly used in melting the charge. The metal must be

poured while very hot and as rapidly as possible. The annealing process consists in heating the castings to a red heat (about 1300 degrees Fahrenheit) for several days. This treatment changes the combined carbon in the white cast iron into graphite. The carbon does not precipitate in flakes as in the case of gray cast iron but in a finely divided form called temper carbon. In this amorphous form, however, carbon is readily oxidized, and in order to prevent oxidation the castings may be packed in any inert material like sand, or clay. Stronger castings are made when a decarbonizing material such as iron oxide is used.

Constitution: Read Article 777. The composition of malleable cast iron is not of great importance; it is important, however, to remember that good malleable cast iron consists principally of ferrite and temper carbon. None of the carbon remains in the combined form. If sand or clay is used as packing material the heat and slow cooling are sufficient to change the combined carbon into temper carbon, and the fractured section of an annealed casting is black. However, if iron oxide is used to pack the castings, it will oxidize the carbon, forming CO, so that the outer surface will be practically pure iron. When such a casting is broken the fracture has a white exterior with a black center. The white skin of carbonless iron is rarely over $\frac{1}{4}$ of an inch thick. This type of casting is called "black-heart." The outer layer may be case-hardened, hardened, or tempered.

Mechanical properties: Read Article 779, omit Table 7. The proportional limit of malleable cast iron is about 20,000 lb. per sq. in. In compression, since it is a ductile material, this value is practically its ultimate strength for long slender specimens. In tension itsultimate strength is about 45,000 lb. per sq. in. Its average modulus of elasticity is about 20,000,000 lb. per sq. in. In the transverse test of a 1-inch square specimen its modulus of rupture is about 70,000 lb. per sq. in. on a 12-inch span. Under these conditions its deflection is about $\frac{1}{2}$ inch. The ductility of malleable cast iron as measured by its elongation is about 7%.

QUESTIONS:

1. What are the principal uses for cast iron in engineering construction?
2. Define cast iron.
3. Why are castings not made directly from the molten iron as it comes from the blast furnace?
4. Compare the foundry cupola and the blastfurnace.
5. Is the cupola or the air-furnace cheaper to operate and why?
6. Compare the two principal methods of producing cast iron.
7. What are the various types of molds used in the production of iron castings?
8. What is chilled iron? What is it used for?
9. How does annealing from a high temperature (say over 750 degrees Fahrenheit) affect chilled cast iron?

10. What is semi-steel? What is it used for?

11. How does the rate of cooling affect the graphitization of cast iron?

12. Discuss the effect of silicon and carbon on the properties of cast iron.

13. What is white cast iron? How can gray cast iron be produced?

14. What is the maximum sulphur content allowed in cast iron by most specifications? Could raw materials having more than the allowable amount of sulphur be used?

15. Name the principal defects in iron castings.

16. What is malleable cast iron? How is it made?

17. Why must a packing material be used in the annealing process?

18. List the strength, elasticity, and ductility of malleable and gray cast iron.

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UNIVERSITY OF CALIFORNIA EXTENSION DIVISION

Correspondence Courses

Materials of Engineering Construction

Assignment 28

Civil Engr-8B Professor C.T.Wiskocil

NON-FERROUS METALS

Introduction.- Iron, copper, aluminum, zinc, lead, tin, and nickel are the metals of greatest industrial importance. Iron is the most important metal used in engineering construction and for this reason it is usually classed by itself. The other metals are usually grouped together and called, as in the heading of this chapter in the text, non-ferrous metals. Many secondary metals such as cobalt, molybdenum, tungsten, and vanadium have no industrial importance except as alloying elements.

Copper.- Read Articles 780, 781, 782 and the paragraph on copper on page 522. Copper ores exist in a great variety of forms, usually as sulphides or oxides. The principal deposits of copper in the United States are in the Lake Superior region and in the Rocky Mountains. In the Lake Superior region it exists as native copper while in the mines of Arizona, Utah, and Montana it is found as copper sulphide and copper-iron sulphide. Copper sulphide is known as chalcocite or copper glance, Cu_2S. Most of the world's supply comes from the copper pyrites or chalcopyrite, $CuFeS_2$. Cuprite and malachite, both given in the text, are decomposed sulphides.

If the copper ore does not contain sulphur the extraction of the metal is simple. Lake copper, for instance which is free from

Dear Professor Clark,

Thank you very much for your letter of the 5th, and for the kind words about my book. I am very glad that you found it interesting, and I hope that it will be useful to you in your work.

I am sorry that I cannot help you with the information you require about the Indian Civil Service. I have no personal knowledge of it, and I do not know anyone who has. I suggest that you write to the India Office, Whitehall, London, and they may be able to help you.

With best wishes,

Yours sincerely,

sulphur is mechanically concentrated and then melted, usually in a reverberatory furnace, and the slag skimmed off. The resulting metal is refined by electrolytic or fire methods. If copper is obtained from sulphide ores the process is more difficult. It usually involves four stages; roasting, smelting, converting, and refining. The object of the roasting is to drive off most of the sulphur in the form of dioxide gas and leave the metal in the form of oxides. All of the sulphur is not driven off because it is desirable to retain some to facilitate smelting which is the next step. The purpose of the smelting is to concentrate the ore by removing the gangue in the form of slag. The metallic concentrate is known as matte which is essentially metallic sulphides of copper, iron, and any other metals originally present in the ore. Smelting is done in a blast furnace or in a reverberatory furnace, the latter furnishing a richer matte. The matte is purified in a Bessemer converter. The air blown through the molten metal eliminates the sulphur and forms what is known as blister copper. Blister copper is refined by fire and electrolytic methods. The electrolytic method is used to produce the finer grades of copper. Anodes of blister copper are placed in a strongly acid copper sulphate solution. Cathodes of very pure copper are used and pure copper from the anodes is deposited on them when an electric current is passed through the circuit. Impurities are insoluble in the electrolyte, and fall to the bottom in the slimes. When these include the precious metals they can be recovered from the residue.

The two principal classes of copper are electrolytic copper, which is obtained by the method just described; and Lake copper, which is obtained from ores mined in the Lake Superior region.

Copper is a malleable, ductile metal having high electric conductivity and great resistance to atmospheric corrosion. Copper does not cast well, most copper products being therefore drawn or rolled. Mechanical working, such as drawing has a greater effect on the physical properties of copper than it does on steel. Hot rolled copper has an ultimate tensile strength of 30,000 lb. per sq. in., and an elastic limit of 7,000 lb. per sq. in., with an elongation of 50%. Cast copper has approximately the same strength but its elongation is much less, being about 7%. Cold drawn copper in the form of wire, has an ultimate tensile strength of 50,000 lb. per sq. in., an elastic limit of 30,000 lb. per sq. in. with an elongation of about 2%. Its modulus of elasticity is about 15,000,000 lb. per sq. in.

The uses of copper are well stated in Article 782.

Zinc.- Read Articles 783,784, 785 and the paragraph on zinc on page 523.

Zinc sulphide, which is known as zinc blende (ZnS), is the principal source of zinc. The deposits of zinc carbonate, called zinc spar or calamine ($ZnCO_3$), are being rapidly exhausted. Zinc silicate ($Zn_2SiO_4 + H_2O$) is of lesser importance. The chief deposits in the United States are in Wisconsin, Missouri and New Jersey.

Zinc ores are roasted to convert them into the oxides, which are then mixed with carbon and heated. The carbon combines with the oxygen of the oxide and pure zinc is volatilized. The zinc vapor is condensed and poured into ingots. In this form it is known to the trade as spelter. Spelter is remelted and rolled into sheet zinc.

Since zinc is rarely used as a stress-carrying member of a machine or structure its tensile strength is not important. The fact that it casts well and has a high resistance to atmospheric corrosion makes it adaptable for a protective coating for iron and steel. When so coated the materials are known as galvanized iron. Zinc is put on in several ways. The metal may be dipped in molten spelter or the zinc may be deposited electrolytically, or the coating may be formed by the condensation of volatilized zinc dust, as the result of a process known as sherardizing. Zinc is used as the negative element in nearly all primary batteries. Zinc dust and pigments, such as zinc oxide and lithopone, are commercial forms of zinc.

Aluminum.- Read Articles 786,787,788, and the paragraph on aluminum on page 523.

In spite of its abundance, aluminum is never found in the free state, and it is only since 1886 that it has been produced on a commercial scale. Bauxite is a hydrated oxide ($Al_2O_3.3H_2O$). It is the principal source of aluminum. Aluminum oxide is called

alumina (Al_2O_3) which is an essential ingredient of clays. The bauxite is converted into alumina which is dissolved in molten cryolite ($AlF_3.3NaF$) from which mixture the metallic aluminum is separated by electrolysis.

Aluminum is very light but has considerable strength; it is malleable, non-corrosive, and ductile, and it has high electric conductivity. It is made into various shapes by rolling, pressing, drawing, and casting. Because of its low electric resistance and lightness it is well adapted for use on long-span transmission lines. It is also used for bus-bars and rods in power houses. Aside from the uses stated in Article 788 it is used to quiet molten metal before casting, for thermit, which is used in welding (previously referred to), and in the form of powdered aluminum, as a paint pigment and in explosives.

Cast aluminum has a tensile strength of about 13,000 lb. per sq. in. with an elastic limit of 9,000 lb. per sq. in. and elongation of 20%. When drawn its tensile strength increases to 30,000 lb. per sq. in. and its elastic limit to about 20,000 lb. per sq. in. while its ductility is decreased.

Lead.- Read Article 789 and the paragraph on lead on page 522. Galena (PbS) is the only important ore of lead. The United States leads in the production of lead. The essential steps in the extraction of lead from its ores are roasting and smelting. There are other secondary operations. Among these is the desilverizing

the lead, if there are sufficient amounts of silver present. The properties of lead which are of most importance are its malleability, plasticity, and resistance to atmospheric corrosion. Its chief uses are listed in the text but an important use is omitted, namely, its use in the manufacture of storage battery plates.

Tin.- Read Article 790. The ores of tin, their occurence, and the method used in extraction of the metal are clearly described in the text. The uses of them are also given. Its high degree of malleability and its resistance to atmospheric corrosion make it of commercial importance. Tin plate is thin sheet steel (a soft low-carbon steel is used) covered with a coating of pure tin.

Nickel.- Read Article 791. Nickel is highly resistant to atmospheric corrosion. It has a silvery appearance and is used to plate iron, steel and other metals. Pure nickel would be an excellent structural material, since its properties are similar to those of medium carbon steel, but it is too expensive. Alloying nickel with copper to form what is known as monel metal makes the product somewhat cheaper. Monel metal contains about 67% nickel, 28% copper and 5% other metals, among which are iron, silicon, manganese, and carbon. Its values for tensile and compressive strength, and its uses are listed in the text. Its strength compares well with that of steel, and this fact coupled with its great resistance to corrosion and the action of sea water, make it a very desirable material.

NON-FERROUS ALLOYS

Introduction.- Metals are alloyed to change their properties. Undesirable properties can be decreased and desirable properties can be increased through the use of alloys. Alloys may be harder, tougher, more ductile,and may have better casting qualities, or greater tensile strength than any of the constituent elements. Furthermore the cost of production can be lessened.

Brasses.- Read Article 792 and 793. An alloy of copper and zinc is known as brass. In special brasses a third metal is added. Brass and bronze, an alloy of copper and tin, which will be discussed later, form the commonest yet the most important of the non-ferrous alloys. They can be cast into the desired shapes or rolled into sheets and rods. Brass can be drawn into wire, while bronze is usually cast into shape. In general, brass has less strength than bronze. Brasses and bronzes are not so strong as iron and steel, but they are less subject to corrosion, and are used where long exposure to moisture is necessary, as in pumps, and for hydraulic fittings. Brass is also used as a bearing metal for steel shafts. Brass is relatively expensive, being about seven times more costly than steel.

The proportions of copper and zinc, in the manufacture of brass, may be varied over wide limits. The figure on page 741 is quite complex. It is sufficient to remember that what is known as standard brass (about 2 parts copper to 1 part zinc)

is most commonly used of all the brasses. In the cast form its ultimate tensile strength is about 50,000 lb. per sq. in. and the elongation is about 30%, with a modulus of elasticity of about 13,000,000 lb. per sq. in. Standard brass is more resistant to corrosion than brasses which contain less copper. Munz metal, 60% copper to 40% zinc, is not used as much as formerly.

Manganese bronze is the most important of the special brasses. The manganese is added to the brass in the form of ferro-manganese as a deoxidizer. The effect is to strengthen and harden the alloy. Usually there are only traces of manganese left in the finished product since most of it is fluxed off. Its strength and toughness are equal to those of steel; besides, it is readily cast and is highly resistant to corrosion by sea water, alkali water, and weak acids.

Bronze.- Read Articles 794 and 795. Alloys of copper and tin have been known since prehistoric times. Commercial bronzes usually contain more than 80% copper. Machinery bronze generally contains about 85% copper. It is used as a bearing metal, for cut gears, bushings, stuffing boxes, and plumbing fixtures. Gun metal and bell metal are the more important of the simple bronzes. Machinery bronzes, in the cast form, has a tensile strength of about 30,000 lb. per sq. in. with an elongation of 10% and a modulus of elasticity of 15,000,000 lb. per sq. in.

The special bronzes, copper-tin-zinc alloys, are the most valuable and in most general use. Machinery bronze referred to above is usually made with some zinc. The addition of phosphorus to any bronze produces a marked increase in its strength and ductility. When of proper composition, phosphorus-bronze can be drawn cold, forged, rolled, and cast. It is used where high strength and resistance to corrosion are controlling factors. Phosphorus, as in the case of manganese, is a strong deoxidizing agent. Only small amounts of residual phosphorus remain in the finished metal.

The three-metal alloys (copper-zinc-tin) can be made so that they have high strength and considerable ductility. The final properties of the alloy depend upon the mechanical treatment, such as rolling and drawing, as well as upon composition and foundry practice, which would include temperature of pouring. Cold working, drawing, or rolling generally raises the elastic limit and ultimate strength of these alloys.

Season cracking of brass and bronze.- Read Articles 796, 797, and 798. Sound metal in the form of sheets, rods, and tubes will often develop cracks under service or even while in storage. Cracking of this kind is also produced by corrosion and sudden changes in temperature. It is called season cracking and sometimes corrosion cracking.

Season cracking may be prevented by annealing and springing.

Springing is described in the text. Annealing must be carefully done so as not to weaken the metal, especially if it is to be used for springs. The concentration of stresses at the base of scratches and corrosion pits can be prevented by polishing the metal. These localized stresses are a source of season cracking. The chief cause of season cracking is the internal stresses set up in the metal by cold working.

The presence of internal stresses, besides subjecting the metal to possible season cracking, causes distortion, if part of the stresses are relieved by the removal of some of the metal, by boring, or by the cutting of keyways. This condition exists also in the case of cold rolled steel shafting.

Alloys of aluminum.- Read Articles 799 to 803 inclusive. The uses of these alloys are given in Article 799. The principal alloys are aluminum bronze, aluminum-zinc alloys, and duralumin.

Aluminum bronze contains about 90% copper and 10% aluminum. Since it contains no tin it is really not a bronze. Aluminum bronze is an alloy of high strength and good ductility.

Duralumin contains about 95% aluminum with copper, magnesium and manganese as indicated in the text. On account of the large percentage of aluminum, it is very light in weight, about 175 lb. per cu. ft., as compared with 480 lb. per cu. ft. for rolled steel. It is used for drawing and rolling. Similar alloys are sold under various trade names but their properties are similar to

those of duralumin. These alloys have made the large dirigibles (air ships of the Zeppelin type) possible. In their construction the strength of steel with the lightness of aluminum is necessary.

Bearing metals.- Read Articles 804 to 808 inclusive. Satisfactory bearing metals must have sufficient compressive strength to withstand the bearing pressure, and they must develop little friction when the surfaces come into actual contact, as when a shaft stops rotating. A well oiled bearing in motion will have little friction irrespective of the kind of metal used because of the oil film on the moving surfaces but when motion stops the oil film is broken and the metal surfaces come into contact and anti-friction metal is then necessary. Most shafting and sliding parts of machines are made of steel; bearings cannot be made of steel because steel surfaces rubbing together would cut and tear each other. Cast iron, bronze, brass, Babbit metal and other anti-friction metals are used. Lead is too soft for a bearing metal. As indicated in Table 4 on page 757, alloys of lead and antimony (used to harden the lead) are the softest bearing metals.

Good bearing metals have a crystalline structure composed of two types of crystal, soft and hard. The hard crystals carry the load and resist wear. The soft crystals yield and allow the harder crystals to adjust themselves to any irregularities in the moving surface, and also wear out below the actual surface of the bearing, thus forming a surface which readily holds the lubricant.

The soft bearing metals, of which Babbitt metal is the best example, are cast directly in place and usually require no machining.

QUESTIONS

1. Name the metals of greatest industrial importance. How are they generally classified?

2. What are the principal copper bearing ores?

3. How is metallic copper obtained from the sulphide ores?

4. What are the approximate tensile strength and elastic limit of hot rolled and cold drawn copper?

5. What is galvanized iron? How is it made?

6. Why is aluminum particularly adapted for use in long-span transmission lines?

7. What are the principal uses for lead and tin?

8. What is monel metal? What are its chief characteristics?

9. What is brass?

10. What is bronze?

11. How does manganese affect the properties of brass?

12. Why is brass that has been worked cold more liable to season cracking than brass that has been worked while hot?

13. What precautions can be taken to prevent season cracking?

14. What are the requirements for a good bearing metal?

15. Name the different bearing metals.

16. What are the advantages of bronze over Babbitt metal as a bearing metal?

17. Why would bronze be preferrable to cast iron for a bearing for a steel shaft?

UNIVERSITY OF CALIFORNIA EXTENSION DIVISION

Correspondence Courses

Materials of Engineering Construction

Civil Engr-8B Assignment 29 Prof. C. T. Wiskocil

FATIGUE OF METALS

Introduction: Read Article 821. Fatigue results from the inability of a metal to carry repeated loading which does not stress it in excess of its elastic limit. The fatigue strength or endurance limit, as it is often called, seems to be a definite unit stress, as well defined a property as the ultimate tensile strength.

When metal parts of machines or structures are subjected to static or impact stresses they either withstand the load or they fail, that is, they are actually ruptured or else rendered unusable by distortion or deformation. The maximum loading under these conditions can be quite accurately estimated by the results of relatively simple tests; but under conditions of repeated stress such as occur when a piece of metal carries a load perhaps a million times and then suddenly ruptures, the maximum safe load is not so easily determined. The load, up to the time of actual fracture, apparently does not damage. This is the characteristic feature of the fatigue of metals.

In the design of metal bridges and buildings the loads are kept within the elastic limit and localized stresses do not cause static failure. It has been estimated that the stresses in members of an ordinary railway bridge are repeated less than two

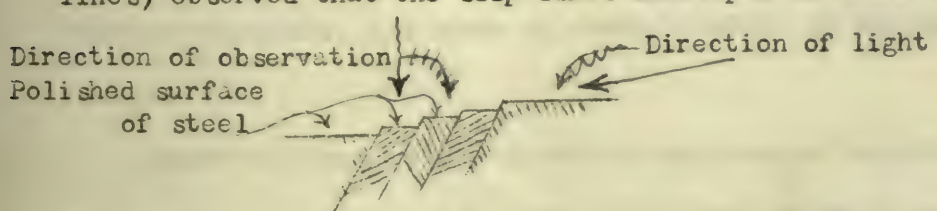
million times during a period of fifty years. In these structures the unit stresses are not large and they are repeated a relatively small number of times. Fatigue, therefore, is not important and the criterion of static strength governs the design.

In the case of machine parts, however, fatigue is a major factor. The crankshaft of an airplane motor is subjected to about twenty million reversals of stress in less than 200 hours of flying. The stresses are relatively high since the motor is constantly operated at nearly maximum power. The stresses in the shaft of a steam turbine, if operated continuously for ten years, would be reversed about sixteen billion times. Fatigue, therefore, must be considered in the design of machine and automobile parts such as crankshafts, piston rods, connecting rods, crankpins, springs and axles.

If a load is put upon a piece of steel and then removed, the metal is said to have been subjected to a cycle of stress. Since steel is not homogenous, the minute constituent particles move on one another during a cycle of stress. For a single cycle, if the maximum stress is within the elastic limit, the heat generated by the microscopic movement is not appreciable but if the stress cycle is repeated the rise in temperature of the metal is noticeable. The friction, which presumably causes this heat, finally weakens some minute element to such an extent that it actually ruptures. This failure of some minute element undoubtedly forms a concentrated

area of high stress and from this nucleus the fracture spreads to adjacent crystals and the progressive increase in the size of the original cleavage plane or crack causes the failure of the entire member. High localized stress is also formed at the base of surface scratches or at the root of a screw-thread or at a minute blow-hole or similar internal defect. These are typical conditions which lead to failure from fatigue. It should be noted too, that failure of machine parts is often the result of a combination of fatigue and damage by occasional overstrain.

The relative movement of the elements of minute steel crystals, when under stress, was first observed by Ewing and Rosenhain in 1899. The movement became evident as dark parallel lines across the faces of individual crystal grains as they were viewed under the microscope when illuminated by oblique lighting. The accompanying diagramatic cross-sectional sketch shows how the light would cast shadows which would appear as parallel lines, called slip-lines, when viewed from the direction indicated. Four years later Ewing and Humphrey (as will be described under the subject of slip-lines) observed that the slip-lines developed in steel by subjecting



Crystal boundaries not shown

it to repeated cycles of stress, would develop into microscopic cracks which in turn would spread and cause ultimate failure of the entire member.

Crystallization of steel: Study Article 822. When steel is subjected to a sufficient number of reversals of stress, even though the stress is within the elastic limit, the induced fatigue makes it liable to sudden rupture. With this type of failure there is no preliminary deformation (read third paragraph on page 779) and the fracture is crystalline as in the case of cast iron or any brittle metal. The appearance of the break and the characteristic suddenness with which failure occurs gave rise to the theory of the cold crystallization of steel - and it is still popularly believed that fatigued steel becomes crystallized. This misconception is fostered by the fact that sudden failures display the crystalline structure of a metal, which in the case of gradual failure as in a static test, is disguised by the elongation and necking of the piece due to its ductility. Therefore, when fatigue failure occurs in a ductile metal, such as steel, it is argued that since it broke suddenly with a crystalline fracture the material became crystallized, and hence was made brittle, by the induced fatigue.

Sudden failure is attributed to brittleness but it is possible to produce a crystalline fracture in a piece of mild steel of known ductility by cutting or sawing a rod part way through and then completely breaking it by a single blow with a hammer. The

resultant fracture will be granular because the grains have had no time to elongate and disguise the crystalline structure. The fracture resembles that of brittle metals which fail suddenly and without apparent warning.

The popular conception of fatigue being caused by vibration and repeated stress under conditiens of continuous service is correct, although the deterioration is not produced as easily as is beleived; but the phenomenon implied by the term crystallization does not exist. The crystallization of steel occurs when it solidifies from the liquid state, therefore, the metal in the solid state is inherently cyrstalline. The crystalline structure of steel has been repeatedly referred to; see illustrations such as those on pages 628, 632 and 637 in the text. Change in crystal size or recrystallization can nevertheless be produced by thermal treatment. (The increase in grain size by overheating without proper annealing has been discussed under the subject of Steel). The misconception arises in the meaning of the term crystallization because the laymen who still adhere to the theory of cold crystallization believe that the fatigue of steel, which occurs under influence of shocks and vibration, produces gradual enlargement of the crystals and corresponding brittleness.

Two reports on failures attributed to cold crystallization because of the large crystals appearing in the fracture were later discredited when it was found thatthe ruptured members had at one time been heated - undoubtedly overheated. These reports appeared

in the Engineering Record of December 13, 1913 as an editorial note, and in the Report made on Division Street Bridge Failure in Spokane, Engineering Record, Vol.73, page 29 (January 1, 1916), and also an editorial on the same subject in the following issue (January 8, 1916). It will be recalled from previous discussions on this subject that fresh fractures of overheated steel show large brilliant facets which are a criterion of the actual structure. The overheating causes an increase in the size of the crystals and a decrease in the strength and ductility of the metal. The large facets in a fatigue failure are formed while the deterioration is in progress by a continuous cleavage plane extending through two or more adjacent crystals which tends to exaggerate the apparent size of the crystals on the surface of the break. But according to Desch a microscopic examination of the metal behind a fatigue fracture shows no change in its structure or increase in size of the individual crystals.

While crystal size can be increased by thermal treatment there is no evidence that crystal growth of steel can be produced by strain at atmospheric temperatures. This statement is true for nearly all metals. Lead is an exception, however, inasmuch as overstrain by plastic deformation results in a decided crystalline growth in this metal even at atmospheric temperatures.

The popular idea of cold crystallization of steel still exists, ~~then~~ in spite of the fact that the true cause of fatigue, which will be discussed later, was discovered in 1903. The statement

is often heard that the axles of Ford automobiles crystallize in service due to continued vibration. This is not to be wondered at since as late as 1915 many engineers still believed in cold crystallization. In THE LIFE OF IRON AND STEEL STRUCTURES by Frank W. Skinner (consulting engineer, New York) Paper No. 107 of the International Engineering Congress, 1915, San Francisco, California, Volumne on Materials of Engineering Construction, page 442, we find the following statement on the subject of crystallization: "That iron and steel are often found after severe service with a damaged crystalline structure, is undoubted, but it is many times a moot question whether this condition was developed in service, or during the original manufacture of the metal." In the discussion of the same paper, however, Edgar Marburg cautioned against the perpetuation of the erroneous cold crystallization theory.

Slip-lines: Study Article 823; it is very important. Marked progress in the study of the fatigue of metals was made by the English scientists, Ewing and Humphrey. Their investigations are remarkable for the accuracy of observation and the ingenious check on their theories. In 1903 the paper "The Fracture of Metals under Repeated Alternation of Stress" explained their experiments and proved that the primary cause of fatigue failure in a ductile metal (steel) was the result of localized deformation which was evident under microscopic observation as a sliding of the crystal elements on each other and the final rupture of individual crystals.

Their test pieces which could be subjected to any desired bending moment, were short rods supported in a revolving mandrel. The region of greatest stress was polished and etched beforehand, for the purpose of observation under the microscope before and after a definite number of revolutions, which produced reversals of stress in the rods. These observations were repeated at frequent intervals. The formation of and development of slip-bands or slip-lines, are clearly described in the text.

The slip-bands, which were first observed by Ewing and Rosenhain on the polished surface of overstrained metal, mark the boundaries or cleavage planes between the elements of the individual crystal as its resistance is weakened by repeated reversal of stress, and it draws out, the elements slipping on each other like a pack of cards. The formation of slip-bands does not involve any change in the crystal arrangement or any increase in crystal size. In normal metal the actual failure or break passes through the crystal.

From these phenomena and the observations of Beilby which lead to the discovery of the nature of the surface produced on metals by polishing, we get a satisfactory explanation of the action of metals under stress. The mechanical movement in polishing causes the extreme outer layer of metal to flow thus forming a skin possibly hundreds of molecules in thickness. Similar but much thinner films of amorphous metal are formed on the surface of intra-crystalline cleavage planes which become so strongly cemented by

the hardening of the film, after a period of temporary mobility, that planes where no slip has occurred are weaker in comparison. In this manner the weak portions have their strength increased and a greater stress is necessary to effect slip or deformation than was first required. This process results in the increase in elastic strength of the material when the metal has been over-strained. It has been shown that there is slight movement along the intercrystalline surfaces but it appears that the actual cohesion between adjacent crystals is much stronger than that between different layers of the same crystal. This explains the high elastic limit given to drawn wire by the overstraining of the metal as it is drawn through the die.

In the action of metal under reversals of stress the slip between different layers of a crystal is continuously reversed in direction and at such frequent intervals that the mobile amorphous film eventually solidifies without cementing the adjacent layers. A microscopic crack develops which weakens that particular crystal, and additional stress is thereby transferred to adjacent crystals, which undergo slip and gradual deterioration in the same way. Final rupture occurs at a unit stress below the primitive elastic limit.

Experiments on fatigue: Read Article 824. The first study of fatigue and its effect on iron and steel was undoubtedly made by Fairbairn who published his results in 1864. His experiments are referred to in the text. In 1870 Wohler presented his data,

which were taken during an investigation extending over a period of 12 years. Wohler's conclusions are substantially in accord with the latest experimental information. Spangenberg substantiated Wohler's conclusions in 1874, while the famous Baushinger published the results of his work twelve years later. The first information on the true action or mechanism involved in fatigue failure was not known until 1903 when Ewing and Humphrey reported their study of metals under repeated stress. Fatigue tests of metals have also been made at the Watertown Arsenal. Important conclusions were reached in an investigation of the fatigue of metals conducted by The Engineering Experiment Station, University of Illinois, in co-operation with The National Research Council, The Engineering Foundation, and The General Electric Company. The results are reported in Bulletin No. 124 of the University of Illinois Engineering Experiment Station, by H. F. Moore and J. B. Kommers (Dated October 1921).

The most important conclusion in the Illinois tests was the confirmation of the existence of a limiting stress (see paragraph 4, Figures 1 and 2, and the discussion relating thereto on page 773) which they named the endurance limit, below which fracture will not occur, no matter how often the stress is repeated. Their conclusion is, "For the metals tested under reversed stress there was observed a well-defined critical stress at which the relation between unit stress and the number of reversals necessary to cause failure changed markedly. Below this critical stress the metals

withstood 100,000,000 reversals of stress, and, so far as can be predicted from test results, would have withstood and indefinite number of such reversals. The name endurance limit has been given to this critical stress." Other conclusions will be referred to later.

The rotating beam type of machine, see Figure 25 on page 71, is most commonly used in repeated stress investigations.

Effect of heat treatment: Read Article 825. The results of the Illinois investigation are summarized as follows: "The test resluts indicate the effectiveness of proper heat treatment in raising the endurance limit of the ferrous metals tested. It should be noted that an increase in static elastic strength due to heat treatment is not a reliable index of increase of endurance limit under reverse stress."

Effect of speed: In the Illinois tests the speed was varied from 200 to a maximum of 5,000 r.p.m. and the endurance limit at extreme speeds was not different from that obtained for the same steels when tested at 1,500 r.p.m. The information given in Article 826 is, therefore, inaccurate.

Effect of surface condition and change of section: The information given in Article 827 was confirmed by the Illinois investigation. "Abrupt changes of outline of specimens subjected to repeated stress greatly lowered their resistance. Cracks, nicks, and grooves caused in machine parts by wear, by accidental blows, by accidental heavy overload, or by improper heat treatment may

cause such abrupt change of outline. Shoulders with short radius fillets are a marked source of weakness."

"Poor surface finish on specimens subjected to reversed stress was found to be a source of weakness. This weakness may be explained by the formation of cracks due to localized stress at the bottom of scratches or tool marks."

Effect of composition: Alloy steels with different heat treatments, such as nickel and chrome-nickel steels, were used in the Illinois investigation. The results showed that the higher the ultimate strength the higher the endurance limit. That is, if a heat treated carbon steel had a higher ultimate strength than a chrome-nickel steel the carbon steel would also have the higher endurance limit.

Relation to elastic limit and ultimate: Read Article 829. The conclusion on this subject from the Illinois investigation is as follows: "In the reconnaissance tests made in the field of ferrous metals no simple relation was found between the endurance limit and the elastic limit, however determined. The ultimate tensile strength seemed to be a better index of the endurance limit under reversed stress than was the elastic limit. The Brinell hardness test seemed to furnish a still better index of the endurance limit." The mechanism of fatigue as viewed under the microscope is a phenomenon of actual rupture - the crystal elements slide on each other and finally tear apart.- Some microscopic element, an individual crystal, reaches its ultimate strength and starts the crack which produces failure of the entire piece.

Under fatigue there is no flow of the material such as occurs at the elastic limit, and it seems reasonable that the endurance limit is more closely correlated to ultimate strength than to elastic limit.

Tests beyond the yield point: Read Article 830. Up to the present time no mechanical device has been found in which the specimen can be stressed beyond the elastic limit at a relatively small number of reversals of stress, say less than one million, and the endurance limit thereby predicted. In stress-number of reversal curves like those on page 775 in the text, the endurance limit is clearly indicated by a decided break in the curve. For all reversals of stress over 10 million the curves in the Illinois tests were horizontal lines. The most reliable method of determining the strength to resist repeated loading is to determine the endurance limit by testing a series of specimens, subjecting them to reversals of stresses of various magnitudes, and constructing diagrams based on stress and number of reversals. The ultimate tensile strength and the Brinell hardness tests are less reliable indices of fatigue strength.

"Accelerated or short-time tests of metals under repeated stress, using high stresses and consequent small numbers of repetitions to cause failure, are not reliable as indices of the ability of metal to withstand millions of repetitions of low stress." This is one of the important conclusions of the Illinois tests.

Rapid determinations of fatigue strength: Read Article 831. The rise-in-temperature method suggested by Stromeyer (see page 778 in text) gives promise of becoming a satisfactory commercial method of determining the endurance limit of steel. Temperature measurements were made in connection with the Illinois tests with the following conclusions: "The endurance limit for the ferrous metals tested could be predicted with a good degree of accuracy by the measurement of rise of temperature under reversed stress applied for a few minutes." The endurance limit is indicated by the sharp break in the curve drawn between unit stress, and by rise in temperature after 1,000 reversals of stress.

Bauschinger's theory of fatigue failure as explained in Article 832 has never been applied to recent test results. But while it does not imply a change in crystalline structure such as was outlined in the erroneous cold-crystallization theory, it does imply change in the inherent nature of the material. The localized stress theory proposed by Moore and Kommers, therefore, seems more probable. "The effect of external non-homogeneity due to scratches, tool marks, square shoulders and notches is well known. Internal non-homogeneity may be due to blow-holes, pipes, inclusion of slag, irregularity of crystalline structure on account of the presence of two or more constituents of varying strength, variation in orientation of crystals, or the presence of initial stresses caused by mechanical working or heat treatment. Owing to the minute area

over which it exists, this localized stress produces no appreciable effect under a single load, but under load repeated many times there is started from this area a microscopic crack, at the root of which there exists high localized stress which under repetition of stress spreads until it finally causes failure. Fatigue failures are not necessarily due to accidental flaws or irregularities. Such failures may, in practice, often be due to such causes, but the definiteness of the endurance limits points to the conclusion that the endurance limit is a property of the material just as much as the ultimate strength. If failure is due to flaws, these flaws are an inherent part of the structure of the steel."

Articles 833 and 835 inclusive give no information on the phenomenon of fatigue and since the diagrams and formulae were worked out on the basis of incomplete data these articles may be omitted.

Endurance limit in terms of ultimate tensile strength: The following is taken from the Illinois report: "In none of the ferrous metals tested did the endurance limit under completely reversed stress fall below 36% of the ultimate tensile strength; for only one metal did it fall below 40%, while for several metals it was more than 50%. However, these metals were to a high degree free from inclusions or other internal defects; the specimens had no abrupt changes of outline, and had a good surface finish."

Endurance limit under repeated stress: A reversed stress is one that varies alternately from tension to compression. A repeated

stress is one which varies from zero to a maximum either in tension or compression. Recent experiments made at the University of Illinois indicate that the endurance limit under repeated stress is approximately 1.5 times that under reversed stress.

QUESTIONS:

1. Define fatigue.
2. What is the theory of cold crystallization of steel?
3. Is a crystalline fracture necessarily the result of brittleness?
4. What causes the crystalline appearance of a fatigue fracture?
5. Explain the mechanism of fatigue failure.
6. What is meant by the term endurance limit? How can the endurance limit be determined?
7. How does heat treatment effect the endurance limit of steel?
8. What is the effect of surface condition and change of section on the endurance limit of steel?
9. What is the best criterion of fatigue strength or so-called endurance limit?
10. Can endurance limit be predicted by tests in which the specimen is stressed beyond the yield point of the material?
11. Discuss the value of the rise in temperature of steel under repeated stress as an index of fatigue strength.
12. What is the relation between the endurance limit under repeated stress and reversed stress?

UNIVERSITY OF CALIFORNIA EXTENSION DIVISION

Correspondence Courses

Materials of Engineering Construction

Civil Engr.-8B Assignment 30 Prof. C.T.Wiskocil

THE CORROSION OF METALS

The importance of corrosion. - Study Article 837.

The rapid coating of the light-colored glistening surface of machined iron and steel by a dull layer of oxide is a familiar phenomenon. Prolonged exposure to air and moisture increases the conversion of the metal into a loosely coherent compound known as rust which has a dark reddish-brown color. The formation of uniform coating of a rust is not as injurious as the corrosive action known as pitting. The corrosion of iron and steel usually occurs in the latter form, in which small deep holes are eaten into the metal. The importance of protecting exposed ferrous metals against corrosion has long been recognized, but unfortunately the experimental studies made have lead to contradictory results and hence there is little agreement between investigators as to the true mechanics of the phenomenon of corrosion.

Corrosion implies the conversion of metallic elements into compounds which are usually insoluble in water. The corrosion of iron and steel is generally known by the term rusting. Rust, which is a hydrated red-oxide of iron, ($Fe_2O_3 x H_2O$) occupies about ten times the volume of the original steel. The x in the formula indicates that there is a variable amount of combined water in rust.

The Question of Safety

The Importance of Conviction - Shady Practice Etc.

The [illegible] of the light-weight [illegible] surface of [illegible] have now equal to [illegible] that layer of water in a [illegible] [illegible] [illegible]

All metals, with the possible exception of gold, are subject to corrosion. In the case of steel, corrosion, when once started, continues until the metal is destroyed; but the thin film of oxide that forms on the exposed surface of aluminum brings atmospheric corrosive action to a standstill. Ferrous metals are protected by being plated with nickel, although nickel itself corrodes. It is relatively stable, however, because as in the case of aluminum, a surface film of oxide forms and protects the underlying metal. Copper is also one of the stable metals. Upon exposure to the atmosphere the surface of the metal is rapidly converted into the green basic carbonate which retards the corrosive action.

In spite of the fact that those metals which resist corrosion, such as nickel, aluminum and copper, become coated with a film which prevents the actual contact between the corroding medium (a combination of air and moisture) and the metal, little experimental work has been done on the formation of protecting films.

If a protecting film is the solution of the rust problem it is evident that it must be a self-healing film. It will be remembered that in the case of the preservative treatment of wood the most effective method was to maintain a perfect toxic coating. If this surface was broken so as to expose the untreated wood the whole piece was then subject to the attack of fungi

which could gain entrance at the break in the protective coating. Parkerized iron resists corrosion because of a film of oil and phosphate but the film must be unbroken to protect the underlying metal. It is common practice to paint or varnish metals to protect them from atmospheric corrosion. More durable protective films are those of zinc, as on galvanized iron, and nickel, on nickel-plated iron and steel. At the present time (1922) all authorities seem to agree that corrosion of iron will occur only in the presence of both water and oxygen. See last statement to this effect given on page 791 - the sentence in the first paragraph of article 846. Iron will not rust in dry air. Furthermore, when submerged in water from which all the dissolved oxygen has been excluded, iron will not rust. The water must be placed in a sealed tube which contains no air. If the surface of the water is exposed to air it will absorb oxygen and the immersed iron will begin to rust.

Variation in durability of iron.- Read Article 838. The remarkable state of preservation of the Pillar of Delhi is referred to in this article. Examples of buried cast iron water mains, in which the water is in motion, which have withstood corrosion for long periods are more numerous than examples of exposed iron such as the Pillar of Delhi. It is quite evident, however, that unprotected exposed iron will, in occasional instances only, resist the destructive action of atmospheric corrosion. Any examples are noteworthy.

It should be noted that the destruction of the ship Negaera, also referred to in this article was not due to atmospheric corrosion. It is obvious that iron will be destroyed by electrolytic action. This is referred to in Article 843 under the heading of local couples. Electrolytic action is sometimes referred to as galvanic action. While action of this kind is common, many engineers do not take into consederation its prevention in their designs, so that replacements are necessary. A striking example occured at the Panama Canal in the corrosion of certain parts of the lock machinery, as noted in Article 843. Electrolytic action was set up between bronze and steel and also between Babbitt metal and cast-steel. The bronze had to be replaced and the Babbitt metal was removed and Greenheart, a durable tropical wood, was substituted. This type of corrosion which here occured, can be prevented by preventing electrolytic action. Dissimilar metals, in the presence of water, will always be corroded when a closed circuit can be established. When the metals cannot be effectively insulated a poor conductor must be used. Bronze bearings in submerged turbines would soon corrode. These bearings are usually made, therefore, of wood such as lignum vitae. Ele ctrolytic action was responsible for the destruction of the $500,000 yacht Sea Call. As noted in Iron Age, February 1, 1917, the plates of the hull were made of Monel metal and were fastened directly to the steel frame of the ship.

The contact of these dissimilar metals set up destructive electrolytic action.

Validity of the acid test.- Read Article 839. As yet the acid test has not been developed so that it can be used as a measure of resistance to atmospheric corrosion.

Relative corrosion of ferrous metals.- Read Article 840. Manufacturers of wrought iron and steel widely advertise the rust resisting qualities of their products. Steel marketed under the trade name of ingot iron is advertised as being particularly durable. Few comparative tests have been made by disinterested parties, so that the relative durability of these metals is not accurately known. The relative rust-resistive qualities of wrought iron and steel are therefore much disputed.

Read Articles 841 to 845 inclusive. Pitting and local couples have already been referred to. It has been known for a long time that dissolved air stimulates corrosion. The uncertainty as to the true action of atmospheric corrosion is demonstrated by the varied practice of the steel manufacturers. Some attempt to secure the maximum purity while others, add copper, a foreign metal, in the attempt to obtain increased durability. The committee on Corrosion of Iron and Steel of the American Society for Testing Materials have recently reported that, "copper-bearing metal shows marked superiority in rust-resisting properties as compared to non-copper-bearing metal of substantially the same

general composition." It should be noted that copper, in copper-bearing steels, is no protection when the steels are immersed in liquids.

Mill-scale, the black oxide of iron (Fe_3O_4), forms a good protective coating, but unfortunately it is brittle and is easily broken. If an unbroken layer could be maintained, no further treatment would be necessary. Since this is impractical the best practice is to remove the mill-scale before applying any of the common metal or paint coatings.

The Electrolytic Theory of Rusting.- Read Article 846. The following statement is taken from Cushman and Gardner, see references listed at the bottom of page 787. " Iron has a certain solution tension, even when the iron is chemically pure and the solvent pure water. The solution tension is modified by impurities or additional substances contained in the metal and in the solvent. The effect of the slightest segregation in the metal will throw the surface out of equilibrium, and the solution tension will be greater at some points than at others. The points or nodes of maximum solution pressure will be electro-positive to those of minimum pressure, and a current will flow, provided the surface points are in contact, through a conducting film. If the film is water, or in any way moist, the higher its conductivity the faster the iron will pass into solution in the electro-positive areas, and the faster the corrosion proceeds. Positive hydrogen ions

migrate to the negative areas, negative hydroxyls to the positives.

"If the concentration of the hydrogen ions is sufficiently high, the hydrogen ions will exchange their electrostatic charges with the iron atoms sweeping into solution, and gaseous hydrogen is seen escaping from the system. This takes place whenever iron is dissolved in an acid. If, however, as is usual in ordinary rusting, the acidity is not high enough to produce this result, the hydrogen ions will polarize to a great extent around the positive nodes without accomplishing a complete exchange. This polarization effect resists and slows down action. Nevertheless, some exchange takes place and iron slowly pushes through."

According to this theory iron goes into solution as a result of electro-chemical action similar to that which occurs in a simple form of primary cell.

Carbonic acid theory.- According to this theory, which is also mentioned in Article 846, iron will not rust without the action of carbonic or some other acid. This explanation of the corrosion of iron is plausible but the theory has been discredited by investigators who have made iron rust in water containing oxygen without a trace of carbon dioxide. In fact they have made iron corrode in slightly alkaline solutions in which the effect of any acid would have been neutralized.

Due to the controversial status of the subject of corrosion the remainder of this chapter in the text is not important. It should be read, however, and the following points noted:

The electrolytic action between strained and unstrained metal as explained in Articles 852 and 853 is sometimes of importance. Article 855 on the protection of iron and steel against corrosion is, in a way, repetition, since many of the methods mentioned have already been referred to. Surface coatings of paint protect steel quite well against atmospheric corrosion. Two thin coats are better than one thick one. The results observed from prolonged exposure under water show that painted steel is not protected against corrosion.

At one time, alkalies were supposed to inhibit corrosion but it has been shown that weakly alkaline solutions of many salts induce corrosion. It has been found very difficult to protect iron and steel laid in alkali soils from the destructive effects of pitting.

The difference between atmospheric corrosion and the often preventable galvanic action between unlike metals, and corrosion caused by stray currents should be recognized.

QUESTIONS

1. What is rust?

2. What is meant by corrosion?

3. Why is pitting more destructive than a uniform coating of rust?

4. Explain the reason for the relative stability of aluminum, nickel and copper when subjected to atmospheric corrosion.

5. What is the chief requisite for protecting films?

6. Why do unlike metals such as steel and bronze corrode when placed in contact under water?

7. Why are submerged turbine bearings made of wood?

8. Discuss the value of copper in copper-bearing steels as a means to increase the durability of steel against corrosion.

9. Give a clear statement of the electrolytic theory of corrosion.

10. Explain the acid theory of corrosion.

11. Why is the acid theory an unsatisfactory explanation of the corrosion of iron and steel?

12. What methods are used to protect steel from corrosion?

(Special)

Summary of important physical properties of materials given in the order in which they were studied. Approximate values given.

Material	Compressive Strength, lb. per sq. in.	Modulus of Rupture lb. per sq. in	Modulus of Elasticity, lb. per sq. in.
Granite	20,000	1,500	8,000,000
Douglas Fir (air dry)			
(parallel to grain)	7,000	10,000	1,500,000
(perpendicular to grain)	900		
Building brick	4,000	1,000	6,000,000
Paving brick	10,000	2,000	6,000,000
Hollow tile (on end)	7,000	--	4,000,000
Portland cement (neat) (6 mo.)	10,000	1,000	---
Portland cement mortar 1.6 (6 mo.)	1,000	300	---
Gypsum	1,500	400	1,000,000
Magnesite stucco	2,700	Tension 500 Shear	3,000,000
Concrete (1 to 6 at 28 days)	2,000	200 --1,000	2,000,000

	Tensile strength lb. per sq. in.		Compressive strength lb. per sq.in.	percentage elongation	Modulus of Elasticity, lb. per sq.in.
	Elastic limit	Ultimate			
Wrought iron	30,000	50,000	30,000	35	27,000,000
Steel (0.2% carbon)	30,000	60,000	30,000	35	30,000,000
Plow steel wire	170,000	250,000	---	5	30,000,000
Cast iron (gray)*	---	20,000	70,000	--	15,000,000
Malleable cast iron	20,000	45,000	20,000	7	20,000,000
Copper(hot rolled)	7,000	30,000	---	50	---
Aluminum (drawn)	20,000	30,000	---	--	---
Monel metal(Rolled)	50,000	85,000	---	40	20,000,000
Brass (Cast)	---	50,000	---	30	13,000,000
Bronze(Cast)	---	30,000	---	10	15,000,000

*Modulus of rupture 45,000 lb. per. sq. in.

(Cont'd)

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